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JAMES C. BUSH, Associate Editor.

EXTRA NUMBER.

GUN MAKING IN THE UNITED STATES

BY

CAPT. ROGERS BIRNIE, U. S. A.,

Ordnance Department.

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WHY THE USE OF THE HOT WATER SYSTEM FOR HEATING BUILDINGS IS GROWING.

THE warming of buildings of all classes by hot water circulation has grown very rapidly in public favor in the United States during the past five years. Previously, it had been extensively used in Europe and also in Canada, but the heaters, radiators and other appliances employed in placing it in those countries up to that time were of such a crude, antiquated design as to prevent the system being employed as a heating medium in modern buildings in this country, although the healthfulness and pleasantness of the heat derived from using the system was appreciated by all who had an opportunity of experiencing it. It was also largely used previous to that time in this country for heating greenhouses, which contain a greater amount of glass and are more largely exposed than any other class of buildings, and also required a more uniform temperature.

The principal advantages of the hot water heating system and the reason for its general adoption for heating isolated and exposed buildings, is the fact that water will absorb more heat from a given quantity of fuel, carry the heat farther and retain it longer than any other system ; that the heat for an entire building can be regulated at the heater to maintain a uniform temperature, regardless of the variation of the temperature of the outer atmosphere; that the apparatus is easily managed, and is safe in the hands of the ordinary help, not requiring the services of a skilled engineer; that it is noiseless in operation under all conditions, and that it will last longer without repairs than any other system. Recognizing the many advantages of the system and the necessities required in placing it in modern American buildings, manufacturers of heating apparatus in the United States have given the development of the system considerable attention during the past ten years; the result being, that while formerly pipe coils were the only construction of radiating surfaces available for use in connection with the system, and that boilers used prior to 1880 were principally constructed for greenhouses and had a grate area much too large for the fire surface contained in the boiler, much of this surface being poorly applied to the fire, and the boilers containing a large quantity of water (much too large for economical heating in a changeable climate), the circulation being very sluggish. Radiators are now made in a variety of designs suitable for heating all classes of buildings, and there has been a number of improvements in the construction of boilers, which has culminated in the construction of the "PERFECT" water heater, which has been very largely used for heating largely exposed detached buildings, and which is admirably adapted for heating all classes of military buildings, such as officers' quarters, barracks, hospitals, etc. It will heat this class of buildings more efficiently and economically than any other system or heater, an important consideration, on account of the fact that fuel is scarce and high priced at Army Posts.

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JOURNAL

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OF THE

UNITED STATES

"I cannot help plead to my countrymen, at every opportunity, to cherish all that is manly and noble in the military profession, because Peace is enervating and no man is wise enough to foretell when soldiers may be in demand again."—SHERMAN.

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WILLIAM L. HASKIN
EDITOR

JAMES C. BUSH
ASSOCIATE EDITOR

MILITARY SERVICE INSTITUTION
GOVERNOR'S ISLAND
1891

The first seven chapters of this paper, with the appendices, were read before the Military Service Institution at Governor's Island, New York Harbor, on November 26, 1887, and were printed as a monograph shortly thereafter. A discussion of the paper appeared in No. XXXIII. of the JOURNAL [March, 1888].

The monograph having long been out of print, and copies still being in demand, Captain Birnie has kindly consented to add Chapter VIII., thus bringing his treatment of the subject up to date. The whole is now reprinted as a supplementary number of the JOURNAL, in the belief that its appearance in this form will be welcomed by many of our readers who have failed to obtain a copy of the monograph, while the new chapter will supply information not readily to be obtained elsewhere.

NOTE.—The negatives from which the plates of the 12-inch mortar and 10-inch gun were reproduced, were made by Lieut. W. W. Gibson, O. D., and were furnished through the courtesy of that officer and Captain Charles Shaler, O. D., commanding at the Sandy Hook proving ground.

The negative for the 12-inch gun on lathe, was made by Captain Ira McNutt, O. D., and was furnished through the courtesy of that officer and Colonel F. H. Parker, in charge of the Army Gun Factory, Watervliet Arsenal, New York.

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THE 12-INCH STEEL B. L. RIFLE,

ON LATHE AT THE ARMY GUN-FACTORY, WATERVLIET ARSENAL, N. Y.

GUN MAKING IN THE UNITED STATES.

By CAPTAIN ROGERS BIRNIE, U S A.,

Ordnance Department.

I.

INTRODUCTORY. EARLY INVENTIONS. RODMAN METHOD OF CASTING. SMOOTH-BORE GUNS. PARROTT RIFLES.

THE subject-matter of this paper aims to be a history of the progress of gun-making and gun trials in the United States, especially with reference to the part taken therein by the War Department in the past fifteen years, or from the date of the Heavy Gun Board of 1872; and prior to that of such matters as appear to have a bearing on current questions of gun construction. The prominent part taken by the Navy Department in being the pioneer of built-up forged steel guns—thanks to its energetic efforts backed up by liberal and progressive Naval Committees of Congress—deserves the fullest recognition and, if a comparatively brief mention is made of the operations of that Department in general, it will be understood as due to the force of circumstances which render even a somewhat detailed account of matters with which the writer is most familiar a matter requiring all the time and attention at his disposal. The data given have been collected from official reports or otherwise, with every regard for correctness; the conclusions and opinions expressed, except when otherwise stated, represent the opinions of the writer and have no official sanction.

Within the past few years the constituted authorities of both the Army and Navy have, with a marked unanimity of opinion, advocated the construction of built-up steel guns and have entered upon their manufacture to the extent of available appropriations by Congress. Until this time, with the exception of the Ordnance system of converted guns, the art of gun-making

in the United States made slow progress, compared with the rest of the world, from the time when our Rodman and Dahlgren cast-iron, smooth-bore guns reached their best development and gave us a brief period of superiority. That was some twenty-five years past, and the guns we have available for sea-coast defense, to-day, comprise these same smooth-bore guns supplemented only by a limited number of the converted muzzle-loading rifles, which date back to 1872, and are now classed as guns of third-rate power. The same was true of our field artillery, but in this respect much has been accomplished, and work is now in progress that will give us at least a limited supply of the best class of modern light field guns. In small arms, and machine guns firing small ammunition, only has the United States maintained an advanced position.

The reason for this state of affairs is, I think, easy to discern. The trade in munitions of war must, like every other industry, obey the inevitable law of supply and demand. The demand for small arms for general use in our own country, and the fact that the cost of the development of these arms places the matter within reasonable control of private industry and does not necessitate a very considerable expenditure on the part of the Government, has maintained the necessary skill in the art, and has enabled our private makers to compete successfully in the markets of the world. With guns of a heavier calibre the case is very different. Governments alone need a supply of these, and governments alone can create a demand for them. The close of the Civil War found us with an established system of smooth-bore cast-iron guns possessing great merit. But hardly had we time to congratulate ourselves upon this circumstance, before the advance of foreign powers in the manufacture of rifled guns, forced us to admit our inferiority. We all know the result of the struggle which established the relative merit of the smooth-bore and rifled guns. We placed implicit confidence in cast-iron as a metal for cannon, and so continued for a number of years to use that metal in endeavoring to establish a system of rifled guns, whilst other nations were coming to discard it more and more in favor of wrought iron and especially steel. Our first rifled guns, introduced in 1861, were made of cast-iron, and a limited degree of success was obtained; then others were tried with signal failure and the attempt for the time being, at least, fell flat. In Congress the culmination of the matter was reached in the terrific

report of the Select Committee on Ordnance, 1869. And in the War Department, in his annual report for 1871, the Chief of Ordnance said: "The results obtained will not warrant me in recommending that any cast-iron rifle guns be procured for arming the forts." All this happened sixteen years since and should have been conclusive, yet there are not wanting manufacturers and laymen, to-day, who still advocate cast-iron rifles. Judging from the course of legislation since that period, it appears that the country has scarcely yet recovered from the paralysis occasioned by the discovery that our justly-vaunted cast-iron gun metal, which had done such excellent service in the short heavy smoothbores, was not a reliable metal for rifled guns. We have been stumbling along in the rear ever since. The idea that if we were to have guns, they should be made with *existing* facilities in the United States, unaccompanied by any whole-hearted effort to improve those facilities, has always been kept to the front—it has retarded our progress, and continues to do so. Certainly, I say, the material for guns, and the guns themselves, must be of home production; but why it should be considered of such doubtful policy to encourage improvements in the manufacture of material and guns, and thereby benefit commerce as well, is a position which is difficult to explain. The very conservative course of legislation in Congress in past years has been explained by saying that the rapidly changing developments in guns and armor would enable us, by waiting a few years, to take up the subject at an advanced stage and thus derive the benefit of the vast amount of experimentation continuously being carried on in other countries. Meantime, the policy has been pursued of maintaining a show of organization for the Service, and in testing immature inventions of various designs; and board after board has been appointed with sufficient frequency to keep the matter in apparently well-meant agitation. Finally, a climax has been reached: we are now in a position to know that navies have been established throughout the world which must exist for years to come; and that equally with this the consensus of nations has adopted a system of construction for guns which is capable of overcoming these vessels, and is besides the strongest and most reliable ever made. In shooting qualities and endurance, this system—the built-up steel gun—is to-day without a rival, and as long as these qualities remain essential to a gun, it promises to remain equal to the best. These facts have been

exploited for several years, and gain new confirmation every day. Congress has given no appropriation for the Armament of Fortifications in two years past, and the apparent reasons for this have been much discussed. The committees have been unable to decide for themselves what measures to adopt. Two important questions were under consideration: first, as to the kind of guns that should be provided, and second, the propriety of changing the present methods of administration in the procurement of guns. To any one who has had the privilege of appearing before these committees and hearing the conflicting character of the testimony taken, the wonder is—supposing that equal weight is given to the testimony of individuals, as appears to be the case—the wonder is, I think, not that the committees should remain undecided, but it would be strange that they should reach any conclusion at all. As to the proposed change in the method of administration—taking away from the present organized Bureau of the War Department the control of these affairs, and creating another bureau under the same Department, or else an independent commission of some sort—that is a matter about which Congress will, no doubt, come to a wise conclusion. It is a question of the substitution of one set of agents for another, or of a multiplication of the paraphernalia of government. It does not seem probable that the laws will be so changed as to substitute a changeable commission of mixed political affiliations for the individual responsibility now held by the head of the War Department, and under him the Chief of Ordnance, assisted as he is in the discharge of these duties by a body of officers already trained at the expense of the Government, appointed for life and subject to removal only through bad behavior. This much we may at least hope: that the question of what guns the Army shall use will remain entrusted to military men.

But the main question before us is as to the type of gun to be adopted. And in this matter, I think, we should make a very clear distinction between an existing established system and experimental construction. By all means let experimentation go on, only this should not interfere with the production of guns for service, when we have at hand the highest type of modern gun, the outcome of years of experimentation to work upon. The conception of a new design for a gun is a very small part of its successful production; the history of gun-making abounds in new designs of form and material, but how few in number have been

the successful types. It is a very small matter to perfect a small invention, but to even approach perfection in a heavy gun is one of the most expensive and laborious questions of modern times. So it has been proved the world over, and so it has been shown in such gun trials as have been made in the United States in recent years, wherein an opportunity has been afforded for the test of a number of different systems to which I will refer.

In reviewing as briefly as may be the history of gun-making in the United States in order to trace its effect upon questions of the day, it will be necessary to begin a connected account with the period of Rodman's improvements in making cast-iron smooth-bores. From that period up to the present era of steel guns we will follow the chronological order of the trials made under the supervision of the War Department.

Some of the earlier designs of guns possess an interest, because of the successful application of the principles involved in guns now in use. Of such were those, dating from 1841, made after the plans of Daniel Treadwell. Professor Treadwell's* first gun was made of rings or short hollow cylinders of wrought-iron joined together end-to-end by welding. Each ring was made of several thinner rings, placed one over or around the other and welded. Subsequently, the method of making the rings was somewhat changed by first making a single ring of steel, about one-third the thickness of the whole, and upon the outside of this, winding a bar of iron spirally, as a ribbon is wound upon a block. Machinery was devised for making the rings, welding them together, and forming the guns by means of various moulds, dies and sets connected with a powerful hydrostatic press. The breech was closed with a screw plug, and a trunnion band formed by the machinery was screwed upon the outside of the gun. The object of this method of manufacture was to so dispose the metal as to place the direction of the fibre in opposition to tangential rupture.

Professor Treadwell's admirably conceived idea was to make a gun of equal strength in all directions. He demonstrated the proposition that, proportioned to the area of resisting metal, the tendency to tangential rupture would be several times greater than the tendency to transverse rupture; hence he arranged the metal to oppose its lines of greatest strength to the effort of the

* A short account of an improved cannon and of the machinery and processes employed in its manufacture, by Daniel Treadwell, Cambridge, 1845.

tangential strains, and thus economized his material and approached, as nearly as could be with the means employed, the conception of his ideal gun of equal resistance. These guns were tested both by the Army and Navy. The smaller calibres stood well, and the Ordnance Board in 1846 recommended batteries of 6 and 12-pdrs. and 12 and 24-pdr. howitzers, approved by the Secretary of War in 1847. Subsequently, it appears, some guns of larger calibre—32 pdrs.—supplied to the Navy did not prove successful. We cannot find in this method of construction more than a very remote resemblance to the principles of the modern built-up gun, but its development was directly shown in the after success of the coil system of wrought-iron gun construction, illustrated in the Armstrong and Woolwich guns of the period 1856 to about 1880, the breech bands of the Parrott guns, and the coiled welded tubes of our converted guns.

The early development of the modern system of hooped guns is traced through General Frederix, in Belgium, in 1830; Thiery in France, whose first gun was constructed in 1833; Chambers' American patent for a hooped wrought-iron gun, dated July 31, 1849, and the English and American designers, Blakely and Treadwell, in 1855. Between these two last there exists a question as to priority of the principle of initial tension in hooped guns, or of giving to the several layers of hoops such a shrinkage as would cause each to offer its full strength in resisting the action of an interior pressure calculated to rupture the gun. But we are most indebted, I believe, to the investigations of Lamè and Barlow for the origin of this principle and to Rodman's exposition of it, precedent to his endeavor to apply it in a cast gun. Chambers' patent of 1849 is especially worthy of note, in that it embodies:

1st. The slotted screw breech fermeture.

2d. The hinged movement of the breech mechanism, when withdrawn to clear the way for loading through the breech.

3d. The loading tray or sleeve inserted in the breech to cover the threads in loading.

4th. The bi-conical shape given to the shrinkage surfaces of the hoops to afford longitudinal strength.

In design this gun was a wrought-iron breech-loading smoothbore, built up with a tube extending in one piece from breech to muzzle, and incased with several layers of hoops, shrunk on. The principle of initial tension is not enunciated in the design,

but it was provided that the rings should be put on at a heat sufficiently low to prevent oxidation. We find the slotted screw, the hinge movement of the breech mechanism and the loading tray in the perfected system now designated the French breech mechanism. The bi-conical shape of hoops is an idea not long since introduced in the De Bange guns, but its utility is doubtful. As regards the Broadwell ring used in the Krupp gun, it appears to have been derived from a patent taken out by Broadwell in Russia. Broadwell's patent was placed first in Russia in 1861, second in England in 1864, aud third in the United States in 1866.

INITIAL TENSION IN CAST-IRON GUNS.

The great improvement in the manufacture of cast-iron smooth-bore guns was due to the introduction of Rodman's method of casting, by cooling from the interior, coupled with the well-conditioned outside lines which he adopted for his gun. Major Wade's report of August 4, 1849, contains an account of the trial of the first gun made on this plan. Two 8-inch Columbiads were cast at the same time from the same iron. One was cast solid in the usual manner, and the other according to the Rodman plan. The first was burst at the 85th round, whilst the second endured 251 rounds. An equal and even greater degree of superiority was evinced in the succeeding trials of 8 and 10-inch guns made in 1851. The object sought to be attained by Rodman finds application to-day in what we consider the highest principles of gun construction. Following the discussion of the action of a central force as enunciated by Barlow some years previously, Rodman, in 1851, pointed out not only the injurious effect of exterior cooling as causing a zone of metal near the exterior to remain in a state of compression and thus actually assist in the rupture of the gun, but also showed that the effect of cooling from the interior would be to so dispose the metal that, in resisting an interior pressure, each concentric laminæ of metal throughout the wall might be equally strained to its limit to resist tangential rupture. To use his own words, referring to a gun which had withstood 1500 rounds without bursting: "The object of my improvement was in part, if not fully, attained, viz.: to throw the gun upon a strain, such that * * each one of the indefinitely thin cylinders composing the thickness of the gun shall be brought to the breaking strain *at the same instant*." Evidently, a condition like this would give a maximum resist-

ance, since it would be determined by the product of the mean strain of the laminæ into the thickness of the wall; and if each lamina worked to its limit, that product would be the greatest possible.

But, whilst we may not deny the utility of the Rodman process as a whole, it was, and must continue to be uncertain in its operation, independent of the always existing uncertainty about the soundness of the castings. A number of cases are known in which the castings burst spontaneously on cooling, and in some cases after being put in the lathe for finishing. And we know also that a frequent cause for rejection of these guns was the existence of cavities uncovered in the boring. The plan may be expected to do more than counteract the effect of the hurtful strains arising from cooling solid castings in the usual manner; it will, in fact, produce to an uncertain extent, however, the proper direction of initial strains. It would be the merest accident should there be brought about the perfect state indicated by the theory. Nor was this to be expected, since the question of the proper degree of temperature to be maintained at the exterior and the rate of cooling from the interior was investigated only in a crude manner. A little study of the problem will show that in order to produce an accurate degree of tension in the indefinitely thin cylinders composing the thickness of the wall, the most delicate appliances would be necessary; the exterior should remain heated to the very last and the cooling progress regularly, according to a certain fixed law, from the interior. Again, it is impossible to maintain the heat of fusion at the exterior sufficiently long for this process to be accomplished, so that the metal there becomes set and prevents a zone of adjacent metal within from contracting as it should upon the interior mass. These are not theoretical ideas, they are the results of careful investigations. The method adopted for determining the amount of tension in the castings was to cut off a thin cross section of the gun to form the "initial tension" ring, and then slot this ring through on one side along a radius. The separation of the ring measured in the slot at the outer circumference, being taken as a measure of the tension. To what extent this method gives a true measure of the initial tension strains is entirely problematical and unknown; it can be said only to show the aggregate result of the interior strains of every sort existing in the castings, and either localized or general. In theory, it was desired to reach

an initial tension of about 20,000 pounds, or two-thirds (66 per cent.) of the average resistance of the cast-iron. In practice, however, it was found that the initial tension of the 10-inch guns varied from 3000 to 28,000, or from 12 to 72 per cent. of the actual tenacity of the iron, and the 15-inch guns from 4000 to 25,000, or from 15 to 61 per cent. of the actual tenacity. These results combine two equally important and unknown factors, viz.: the uncertainty of the method to produce the results desired, and the inadequacy of the method used for determining the initial tension. Investigations and extended attempts to introduce the Rodman method of casting have been made in Russia and proved unsatisfactory, because it was found, upon careful investigation, that the desired state of initial tension could not be produced with any degree of certainty.*

The results of an important investigation recently made at Watertown Arsenal in this matter are given in Notes on the Construction of Ordnance No. 38, by Lieut. William Crozier, Ordnance Department, U. S. Army. "To determine the form of the initial tension curve and the value of its ordinates, a ring (section) was cut from the portion of the sinking head of the gun immediately adjoining that from which the trial cylinder was taken: this ring was scored with concentric circles about one inch apart, whose diameters were measured; it was then finished to the radial dimensions of the trial cylinder and the diameters of the circles again measured. In this state it had the initial condition of the trial cylinder.† It was then cut into concentric rings, a little less than one inch in thickness, by cutting midway between the scored circles, after which the diameters of the circles were a third time measured—the changes of dimensions indicating the amount and character of the strains to which the small rings were subjected before being detached. The dimensions were meas ured with great care on four different diameters, making equal angles with each other."

The results of the measurements thus made are shown in the figures on next page.

The expansion of the thin rings on being released gave a measure of the compression to which each had been subjected in the casting, and the contraction of others showed their state of extension in the casting. The platted curves show that the inte-

* Notes on the Construction of Ordnance. No. 21, page 7.

† Referring to the core of an experimental wire-wound gun cylinder.

rior of the casting was compressed as designed in the Rodman process, but the exterior was in a state of irregular tension. The highest state of extension is about one-fifth the thickness from the exterior, and the exterior metal itself was in a state of compression—thus producing a strain in that place which would tend to assist an interior (powder) pressure in bursting the gun. This method of investigation is evidently best suited to elucidate the efficacy of the so-called "natural hooping" involved in the Rodmon process. The detached rings were made as thin as could be manipulated with due regard to accuracy of results, and a good

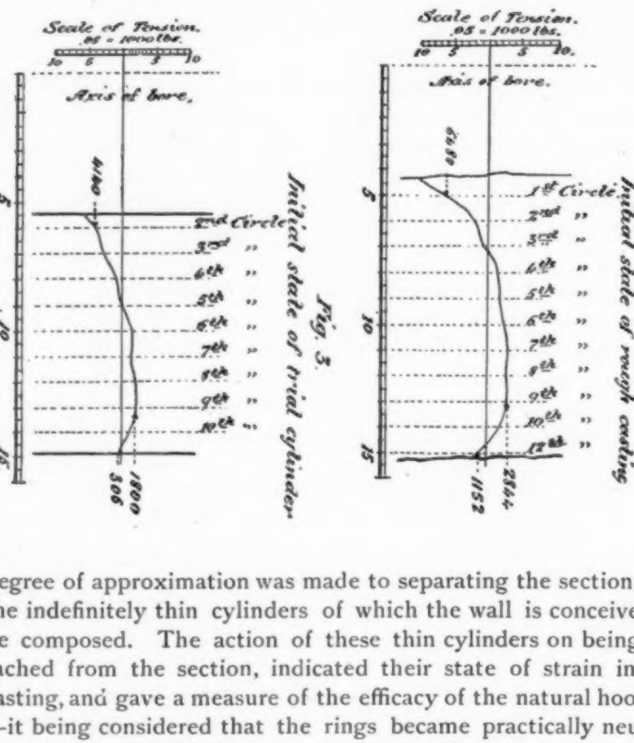

Fig. 3. Initial state of trial cylinder

Fig. 2. Initial state of rough casting

degree of approximation was made to separating the section into the indefinitely thin cylinders of which the wall is conceived to be composed. The action of these thin cylinders on being detached from the section, indicated their state of strain in the casting, and gave a measure of the efficacy of the natural hooping —it being considered that the rings became practically neutral, regarding tangential strains, on being detached. At a subsequent period these thin rings were cut in two on one side in a similar manner to the ordinary test of an initial tension ring or full section of a gun. Their behavior was very irregular, and gave no

indication of the initial tension shown by the preceding experiment to have existed in the wall of the casting. This behavior of the thin rings, on being cut apart, indicated the existence of local strains of an uncertain character, and showed the unreliability of the initial tension test as usually followed. I have devoted the more space to this subject of initial tension than might otherwise be considered necessary, because of its bearing upon the question of steel-cast or other guns now advocated to be made after this process.

CAST-IRON SMOOTH-BORE GUNS IN SERVICE.

The number of Rodman smooth-bore guns now available for the land service is 210 8-inch, 998 10-inch, 305 15-inch and 2 20-inch. These guns, if properly mounted, can be expected to perform efficient service in case of necessity. For armor piercing, the 8 and 10-inch would be of little value. The powder charge of the 10-inch is 25 pounds of mammoth powder and the round projectile weighs 128 pounds, giving a muzzle energy of 2000 ft. tons, which, however, for this form of projectile, would fall away very rapidly. But these guns may be made useful in the defense of minor points and torpedo lines. The 15-inch gun fires a projectile weighing 450 pounds, and through the experiments made by the Ordnance Board at Sandy Hook, in 1883, its powder charge has been increased to 130 pounds of hexagonal powder, which gives an average pressure of about 25,000 pounds per square inch in the bore. With this charge the range at 20° elevation is 3.75 miles. At the same time it was found that the projectile would pierce 10 inches of iron at 1000 yards. The initial velocity of 1700 f. s. imparts a muzzle energy of 9000-ft. tons, but so rapidly would this fall off that at 1000 yards the energy would be considerably less than that of the projectile of the new 8-inch steel rifle, which starts with an energy of 7200-ft. tons.

PARROTT RIFLES.

Although all the Parrott guns are now classed as "retained calibres" in the Service—that is, only to be used in cases of necessity—they performed a most important duty in our last War, and are especially worthy of mention as being the first extended system of rifled guns introduced in the United States. Their founder and maker will always be regarded as one of our

most successful gun-makers, and remembered as a man distinguished in the art. He made a wide reputation for himself and for the West Point Foundry, at Cold Spring, New York, which under his successors, has continued to afford indispensable aid to the Government in the production of new types of guns, and has materially assisted in maintaining and diffusing a knowledge of gun-making in the country. My personal obligations in this respect are deep, for it has been my good fortune to have remained on duty there as an inspector for nearly six years, with opportunities for acquiring the practical knowledge that abounds at the foundry.

The history of the Parrott guns is so well-known that it will be necessary to call attention only to certain features. The smaller calibres showed in some cases a remarkable endurance in War service, and the same was true to a less extent with the larger calibres, but failures of the 100, 200, and 300-pounders were relatively numerous. Several instances which have occurred in practice firing with these guns in recent years have also, in connection with modern improvements in construction, led to the obvious necessity of retiring them from service as soon as they can be replaced. The uncertainty in endurance of the heavier calibres, must be regarded as evidence of the unsuitability of cast iron as a metal for making heavy rifled guns. Any system of conversion for these guns would necessitate an enlargement of the bore, and corresponding thinning-down of the already weak walls; moreover, the guns were made for quick burning powder and are too short to realize a proper effect with slower burning powders. The wrought-iron reinforce band of these guns was made from a bar coiled and welded in the form of a hollow cylinder, which was afterwards finished for shrinkage. The effect of this was to dispose the fibres of the iron to resist tangential rupture, and the band was probably not expected to afford any resistance to longitudinal rupture. The cast-iron wall of the 100-pound rifle, for instance, is one calibre (nearly) in thickness, and the thickness of the reinforce band is one-half calibre (3.2 inches.) The shrinkage prescribed for the band was one-sixteenth of an inch to the foot, or 0.0052 of an inch per linear inch. This is fully four times as much as would now be regarded a useful limit for the shrinkage of a wrought-iron gun hoop; however, these bands were assembled at a high heat and the iron band was allowed to adjust itself without exterior cooling; hence we do not

find in these guns an example of the practice of hooping, as now understood. And the excessive shrinkage of the single band, by producing unduly heavy cross strains in the section of the cast-iron at the front, tends to weaken the gun to resist longitudinal rupture, as may be inferred from the mannei in which a good proportion of the failures have taken place.

II.

PERIOD FROM 1872 TO 1881. HITCHCOCK, MANN, LYMAN-HASKELL AND WOODBRIDGE GUNS. CONVERTED MUZZLE-LOADING RIFLES. CONVERTED BREECH-LOADING RIFLES. SUTCLIFF AND THOMPSON GUNS. FIELD GUNS.

THE Heavy Gun Board of 1872 was appointed to meet in New York City for the purpose of examining such models of heavy ordnance as might be presented to it, and of designating and reporting to the Chief of Ordnance such models as might be selected for experiment. Colonel Whitely, of the Ordnance Department, was president of the board, and there were besides, one officer of Engineers, two of Ordnance and two of Artillery, as members. A special appropriation was made in advance by Congress for the purpose of carrying out the recommendations of the board. The board examined into forty inventions and proposals, and selected the nine following, arranged in the order of merit determined by the board, viz.:

Muzzle-loading guns :—

1. Doctor W. E. Woodbridge.
2. Alonzo Hitchcock's.
3. Cast-iron guns, lined with wrought iron or steel tubes.

Breech-loading guns :—

1. Friedrich Krupp.
2. E. A. Sutcliffe.
3. Nathan Thompson.
4. French and Swedish system.

Miscellaneous :—

1. H. F. Mann's.
2. Lyman's Multicharge.

The Ordnance Department was occupied in the ten years following, pursuant to enactments of Congress, in the construction and trial of the guns recommended by this board. The Krupp gun was intended to be tested for a trial of the breech mechanism as well as the system of construction. However, no gun of Krupp's system was procured, for the reason the War

Department was unable to comply with his conditions, which necessitated the purchase of a number of guns in case the trial gun should prove a success. Such an agreement by the War Department could only have been made in case Congress had already appropriated the money for the purpose, and this was not done. But the Krupp breech mechanism was subsequently tried in combination with the converted wrought-iron-lined guns recommended by the board, after the muzzle-loading guns of the same type had been successfully tested.

The Hitchcock gun proposed, was a nine-inch muzzle-loading rifle, to be made by welding together disks or "cheeses" of wrought-iron, forming sections of the gun, to make a solid wrought-iron piece. The work was conducted at the Springfield Armory under the direct supervision of the inventor. After nearly three years' labor and the expenditure of a large amount of money, the project was abandoned as being too difficult and costly, if not impracticable, to be fulfilled.

No provision was made in this period for a trial of the French and Swedish system. The Mann gun considered by the board, was an 8-inch breech-loading rifle already in possession of the Ordnance Department, which had been fired about fifty rounds. Some alterations were made, and the gun was fired eleven rounds at Sandy Hook, in 1875, after which it was moved to Philadelphia to be placed on exhibition at the Centennial. The Lyman's multi-charge gun, in existence at this time, was a 6-inch breech-loading rifle, designated by its private owners as the "Multi-charge 100-pounder rifle gun." But since improved models of both the Mann and Lyman-Haskell guns were tested at a period subsequent to this, further references will be deferred to an account of those trials.

WOODBRIDGE 10-INCH WIRE-WOUND GUN.

It appears from the record that Dr. Woodbridge first presented a plan for a wire-wound gun to the War Department, July 30, 1850, which establishes his claim to priority in the idea. A 2.5-inch gun, constructed upon his plans at the Washington Navy Yard, was tested for endurance at the Springfield Armory, where, in 1865, Major Laidley reported that 1327 rounds had been fired from it and the firing had been stopped because the trunnion band broke loose, but the gun itself was practically uninjured. The trial gun decided upon in 1872 was a muzzle-loading rifle of

10-inch calibre. It consisted of a thin steel tube strengthened by wire wound on its exterior surface; tube and wire being subsequently consolidated into one mass by a brazing solder melted into the interstices. The tube extended through from breech to muzzle; was left solid for a length of 19 inches to form the breech and had a thickness of 1.5 inches around the bore. The length of the bore was 155 inches, or 15.5 calibres. The following brief description of the process of manufacture is taken from the report of Captain Prince, dated March 31, 1875:

"Square wire is wound upon a steel core somewhat larger than the intended bore of the gun, a sufficient number of wires being wound at once, side by side, to produce the required obliquity of the turns. The successive layers have opposite twist, their number being, of course, sufficient to give the desired exterior diameter to the gun. When thus wound, the whole mass is enclosed in a tight case to protect it from oxidation, and is heated therein, to a temperature somewhat above that required for the fusion of the metal to be used for consolidating it. The soldering metal is then run in, filling all the interstices of the mass. When properly cooled, the gun is bored and finished from the mass in much the same way as if it were a common casting."

The construction of the gun was undertaken at Frankford Arsenal in October, 1872, and after many delays and difficulties was completed in April, 1876. It was fired 10 rounds at Frankford Arsenal with powder charges increasing from 40 to 70 pounds, and projectiles from 343 to 397 pounds. In these firings imperfect brazing was developed and a crack was started on the exterior of the gun. The same gun was taken up in 1881 and fired for endurance under the supervision of the board on heavy ordnance and projectiles. The charge principally used was 70 pounds hexagonal powder and 395 pounds projectile. With a charge of 80 pounds of powder the gun parted longitudinally after a total of 93 rounds, the "fracture being 26.75 inches from bottom of bore in the plane of openings noted and measured during the firing." Notwithstanding the poor success of this gun, as shown in the difficulties attending its manufacture, and its subsequent failure under proof, the Getty Board, being much impressed with the utility of continued experiments with wire guns, recommended that a breach-loading gun of the same construction be made and tried, with others of different designs presented by Dr. Woodbridge. These later designs apparently possess more merit and have superseded the first construction in which the brazing of the wire formed almost the sole reliance for longitudinal strength. The recommendation to try another brazed wire gun has never been carried out.

CONVERTED MUZZLE-LOADING RIFLES.

These guns consist essentially of a cast-iron body or casing, strengthened with a wrought-iron or steel rifled tube which has a thickness of wall, over the seat of charge, equal to about one-third the calibre of the gun. They constitute a system of built-up guns in which the shrinkage of the casing on the tube is negative, or there is a play. The casing, except in a single gun of new construction—the 12¼-inch rifle—is formed of the Rodman smooth-bore gun, from which about 15-100 of the calibre only in thickness of cast-iron is removed to enlarge the bore for the reception of the comparatively thick tube of reduced bore. In the wrought-iron tubes formed by coiling and welding bars of the very best grade of wrought-iron, the fibre is arranged to resist directly the dangerous tangential strain, and these tubes are, besides, reinforced over the seat of the charge by a sleeve or jacket of wrought-iron, similarly formed and shrunk over. These wrought-iron tubes would alone support an interior pressure of 13,000 pounds per square inch, or more than one-third of the whole pressure that the guns are called upon to bear. Even supposing the tube inert, its interposition causes a reduction of about 31 per cent. of the pressure in the bore in transmission to the cast-iron, because the pressure upon one square inch of the bore would be distributed upon 1.7 square inches of the interior of the outside cast-iron body. On the other hand the cast-iron body has been weakened by the reduction of thickness made for the reception of the lining tube, but as this reduction is small the weakening effect as a whole is much more than counterbalanced by the added strength due to the lining, coupled with the reduction of bore. In the later constructions where steel is used, the metal is a fine quality of highly ductile steel suited to the construction, and the tube in itself is able to safely support an interior pressure of 18,000 pounds per square inch, or about one-half of the whole strain upon the gun when fired.

In mode of conversion, these guns are divided into three classes, viz.:

1. The muzzle insertion with wrought-iron tube.
2. The breech insertion with wrought-iron tube.
3. The muzzle insertion with steel tube.

The difference between the plans of muzzle and breech insertion lies principally in this: In the former the tube is supported longitudinally from a force that would tend to open

coil welds, by the muzzle screw-collar; whilst in the latter, there are several shoulders on the outside of the tube which bear against corresponding shoulders in the casing, and the tube by this means is well supported longitudinally from movement forward, at several distances throughout its length. A special importance attaches to this in the use of coil welded tubes, which are more apt to develop a weakness at the coil weld joints than in any other part.

These guns were proposed as an expedient for converting the comparatively useless 10-inch smooth-bores into rifled guns, to meet the increasing thickness of armor carried by vessels. When this system was inaugurated the 8-inch calibre was seen to be a gun that would equal in power the existing English guns of like calibre, and it was hoped that the extension of the system to guns of larger calibre, would prove a success. As an additional reason for the adoption of the system, our forts were, *and still remain*, constructed with casemates adapted to accommodate a gun of about the dimensions of the 10-inch Rodman, and the conversion of this gun into a rifle afforded, at that time, the best and the only available means for increasing the efficiency of the casemated forts to a maximum. At the same time, however, the Chief of Ordnance, General Benét, then placed himself upon record as saying*: "There is little doubt that steel is the best material for guns." He did not recommend an expenditure of a large amount of money for a gun plant to make the proposed conversion, but drew attention to the success of the tubing, as enabling the smooth-bore guns to be made strong enough for use as rifles, and recommended the system as an "easy and economical mode of converting our cheap cast-iron smooth-bores into powerful and efficient rifles."

The lining of a cast-iron body with a steel tube, as a system of construction for rifled guns, (10-inch and 12-inch) was recommended for trial by the Ordnance Board, convened under the order of the War Department, dated December 16, 1867. The matter was brought to the attention of the Board of 1872, by Major Crispin, and this board recommended the conversion of four 10-inch Rodman guns upon the plans proposed, which were modelled upon the Palliser plan of muzzle insertion, then successfully established in England, and the Parsons (American) plan of breech insertion. The details of the construction of the guns

* Page 94, Report of the Chief of Ordnance, 1875.

were subsequently arranged by boards of Ordnance officers, convened September 18, 1872, and October 10, 1874. It was decided that two of the four experimental guns be made of 8-inch calibre and two of 9-inch calibre, one of each to be tubed from the front, and one from the rear; the muzzle insertion to be wrought-iron tubes, and the breech insertions jacketed steel tubes.

The wrought-iron tubes were procured from Armstrong, and the parts of the steel tubes from the Bochum Steel Co., Germany. The 8-inch gun, with wrought-iron tube inserted from the muzzle, was at once established as a success. The 9-inch gun, of the same model, was also successfully proved by firing 502 rounds, but this calibre made the gun too light to compete successfully with foreign guns of like calibre. The 8-inch gun, with steel-jacketed tube inserted from the rear, was burst after firing 456 rounds, of which 281 were fired after the development of a crack in the steel tube at the 175th round. The 9-inch gun, of the same model, was not fired to extremity. The steel procured for these tubes was not of the uniform strength considered desirable, and its elastic limit was what we would now consider exceedingly low—that was from 23,000 to 25,000 pounds per square inch. Following the success of the 8-inch muzzle insertion with wrought-iron tube, a gun of 10-inch calibre converted from a 13-inch smooth-bore, and also a new construction—the 12.25-inch rifle—were made upon the muzzle-insertion plan. The 12.25-inch was made 18.5 calibres in length of bore, and was, when made, one of the most powerful guns of that calibre in existence. The trials of these guns of larger calibre developed the unsuitability of the muzzle-insertion plan when applied to them, owing to defects developed in the coiled welded tubes which, in this plan of conversion, received longitudinal support only from the muzzle screw-collar. In the proof of the 10-inch gun the tube was torn apart longitudinally, after a few rounds, and a large portion of the muzzle-end of the tube was projected forward out of the gun. The tube was repaired, and the gun afterwards fired some thirty rounds. This led to the substitution of the breech-insertion plan as essential to the construction of guns of larger calibre than 8 inches. And by analogy the same reasoning led to the relinquishment of the muzzle-insertion for 8-inch guns. Experimental guns of 8 and 11-inch calibre were made on the breech-insertion plan and proved for endurance. Only a few of the 11-inch were made, as this construction gave place to the 11-

inch converted breech-loaders. Thus it came about that the 8-inch gun was the only calibre of these converted muzzle-loading rifles which was adopted and manufactured for issue in service.

The wrought-iron tubes for the first two experimental guns were, as already mentioned, procured from England, but the third was procured from West Point Foundry, and the manufacture of these tubes became, at a later period, a regular product of home production at that foundry. So also with the bar-iron for making the tubes. The demand for this production at home soon led to its procurement in the quantity desired, and in quality fully equal to foreign make. This iron was manufactured at the Ulster Iron Works, Saugerties, N. Y. The work of conversion was done at the West Point and South Boston Foundries.

The use of a steel tube, muzzle-insertion, was introduced in the 50 guns last converted. At this time (1883) it had become apparent not only that steel was the best material for guns, but also that improvements in the manufacture of gun steel in other countries had removed the doubts raised by our own trials of inferior metal. It therefore became a highly important matter to encourage the production of gun steel at home. It was found also that the steel tube conversion could be made at a considerably less cost than the wrought-iron. With these ends in view, an experimental gun was first made and satisfactorily proved for endurance. The order for 50 tubes was then placed with the Midvale Steel Works, and successfully filled. This was the largest order for steel forgings that had, up to that time, been placed in the United States. A special fine quality of steel was demanded, possessing great ductibility, combined wlth a relatively low elasticity and tenacity, and the fulfillment of the order did much to advance the manufacture of gun steel in this country, and as well to increase the experience of the Midvale Steel Co., and to establish the excellent reputation for the manufacture of gun steel which that company now holds.

Five hundred rounds was fixed as the number necessary to prove the endurance of the 8-inch guns. The following table gives a list of the type of experimental guns fired, and the number of rounds fired from each.

ENDURANCE OF EXPERIMENTAL CONVERTED MUZZLE-LOADING RIFLES, DATING FROM 1874.

Nature of Gun.		Average Weight of Charge.	Average Weight of Projectile.	Number of rounds Endured.	Condition at end of trials.
	Type Guns.	Pounds	Pounds.		
8-in.	Muzzle insertion, wrought-iron tube (English)	35	180	817	Serviceable.
8-in.	do. do. (W. P. F.)*	35	180	651	do.
8-in.	Breech-insertion wrought-iron tube (W. P. F.)....	35	180	783	do.
8-in.	Muzzle insertion, steel tube (Midvale).............	35	180	606	do.
	Experimental Guns.				
8-in.	Breech-insertion, steel tube (Bochum.)............	35	180	456	Steel tube cracked at 175th round and gun destroyed at 456th round.
8-in.	Chambered. Breech-insertion, wrought-iron tube (W. P. F.)............	55	180	108	Serviceable.
9-in.	Muzzle insertion, wrought-iron tube (English)....	40 45	200 230	502	do.
9-in.	Breech-insertion, steel tube (Bochum)............	40	230	118	do.
10-in.	Muzzle-insertion, wrought-iron tube (English)......	75	400	33	Serviceable, with repaired tube. The original tube was ruptured longitudinally early in the proof.
11-in.	Breech-insertion, wrought-iron tube (W. P. F.)....	90	525	401	Passed prescribed endurance test of 400 pounds. Defects developed in coil-welds.
11-in.	Chambered. Breech-insertion, wrought-iron tube (W. P. F.)............	125	550	138	Serviceable.
12.25-in.	New Construction. Muzzle insertion, wrought-iron tube (W. P. F.).......	150†	700	76	Serviceable.

The 8-inch service rifle of this class is 14.7 calibres in length of bore. The charge is 35 pounds of hexagonal powder and the projectile weighs 180 pounds. The results of the latest trials with this charge give an average pressure in the bore of 30,500 pounds per square inch, and an initial velocity of 1385 f. s. From trials made at Sandy Hook, in 1883, using chilled-iron projectiles, it was shown that the power of the gun was sufficient to more than penetrate eight inches of iron armor at 1000 yards, thus making it an effective weapon to defend narrow channels

* Abbreviation for West Point Foundry.

† One round with 200 pounds charge of powder. The greater number with 100 pounds charge.

against the passage of vessels carrying about eight inches of iron or less.

CONVERTED BREECH-LOADING RIFLES.

The recommendation of the Board of 1872 to test the Krupp system was carried out in regard to the breech mechanism by its adaptation to the converted breech-loading guns which were tried, following the success obtained with the muzzle-loading rifles. In general features of the tube construction the breech-loading gun was made like the breech-insertion muzzle-loader. But the jacket was made of a heavy steel piece, which projected to the rear to receive the Krupp fermeture, and this jacket being larger than the wrought-iron jacket used in the muzzle-loader, considerably more of the thickness of cast-iron about the breech was removed, leaving a thinner casing of cast-iron. To compensate for this, and to add strength to the breech, a steel hoop was shrunk upon the breech-end of the truncated casing; and in addition to the screw-thread used to secure the tube in place, the casing in this construction was also shrunk upon the tube over the length of its jacket. The first 8-inch gun was made and tried. The steel used in this gun was furnished by Whitworth, and was of good quality. The proof of this gun was entirely successful; it withstood 636 rounds, using the same charge as the muzzle-loading rifle without injury, and remained in serviceable condition. Other guns of 8 and 11-inch calibre were then ordered.*

The orders given for the manufacture of the converted 8 and 11-inch guns were suspended and cancelled when the second trial gun of 8-inch calibre, and the first of 11-inch calibre failed under the proof to which they were subjected. These guns differed from the first experimental breech-loading gun in being cham-

* An experimental 12-inch B. L. Chambered Howitzer to be converted from a 15-inch smooth-bore, and four 12-inch B. L. Chambered rifles of new construction, but of the same general design as the converted 8-inch breech-loader, were also projected, and their construction was begun in 1880. The 12-inch rifle was designed for 24-calibres length of bore, with a total weight of about fifty tons, and use 200 to 300 pounds of powder with 800 pounds of projectile. None of these guns, however, were completed. It became necessary to abandon the construction, because steel of the requisite qualities could not be supplied. The steel forgings for these guns were procured in England, and brought to this country by the contractors, but when submitted for the inspection of the officers for the Ordnance Department, the metal was found to be wholly unsuitable, being materially below the standard guaranteed, and, consequently, the forgings were rejected.

bered to receive increased charges of powder—the increase being for 8-inch, 55 pounds, instead of 35, and for 11-inch, 130 pounds, instead of 90. One 8-inch and the 11-inch gun failed after a few proof rounds, by a clear fracture of the steel breech-piece in a plane through the front angles of the slot for breech-block. It is important to remark that in these guns the angles at the front corners of the slot were cut square—a feature which is stated to have caused several of the few recorded disastrous failures in guns made by Krupp. Added to this, the tests of the steel which ruptured in these guns, showed a quality of metal badly adapted to gun construction. Four specimens taken longitudinally from the metal of the 8-inch piece gave an ultimate tenacity varying from 79,000 to 112,000 pounds per square inch, and this irregularity of strength was accompanied by an exceedingly low ultimate extension, in one specimen as low as 4 per cent., and not exceeding 9 per cent., in the best of the four.

The 11-inch piece showed a much poorer quality of steel, though of an entirely different nature. The average tenacity was uniform but low, ranging, for twelve specimens, about 66,000 pounds per square inch. The elastic limit ranged between the low figures of 10,000 and 24,000 pounds per square inch, and the metal was soft and friable in its nature. Analysis showed that it contained 0.247 of one per cent. of sulphur. Subsequently a second 8-inch gun, made at the same time with that just described, was prepared for trial by rounding the front corners of the slot. This gun gave an excellent record in its proof for endurance; it was burst into many fragments at the 127th round, but for six rounds preceding that catastrophe had endured a 55-pound charge of powder that gave an *average* of 51,000 pounds pressure per square inch in the bore, and for 15 rounds preceding the six named, an equal charge of somewhat slower powder, that gave an *average* of 43,600 pounds pressure.

It was equally unfortunate for the Krupp breech-mechanism, and for the advancement of steel-gun construction in this country, that the two guns should have failed so soon in the proof. It is not fair to argue that it was the Krupp mechanism which caused the failure, since the steel was of unsuitable quality, and the after proof of the gun, with rounded angles, indicated a good endurance of the mechanism, as did also the proof of the experimental gun which endured 636 rounds without failure; but the failure of these guns called particular attention to that

apparently ugly feature in the mechanism—the amount of metal cut away by the slot—which, especially in large guns, gives the appearance of longitudinal weakness. As to manipulation, and in other respects, the Krupp mechanism, provided by home manufacturers, gave a good degree of satisfaction. The only objectionable feature of importance noted was the tendency of the seat for the gas check to become oval, attributed to the presence of the slot and the resultant of the longitudinal pull which is sustained by the sectors of the metal left above and below, and is so unequally distributed throughout the cross section of the jacket. In the converted 3.2-inch breech-loading field guns this mechanism has given no serious cause for complaint in the limited use to which it has been put in our service. In Germany, however, it has been found necessary, in rough service, to modify the Broadwell ring. The large surface of contact between the exterior surface of this ring and its seat, makes it difficult to preserve the close adjustment needed, and this ill fitting is aggravated by the presence of any dust or dirt in the seat. The modification, which has been applied with good results, consists essentially in reversing the contour of the ring, and limiting the surface of contact to a blunt rounded lip which comes in contact with the seat, to seal the escape of gas, only at the forward end of the ring. As regards the utility and safety of the Krupp breech-mechanism as a whole, its long-continued and successful application in guns made by Krupp, place it beyond doubt as one of the two best systems now in vogue.

The effect of the failure of these guns in producing an unfavorable opinion upon the use of steel in gun construction was also marked. Not only was this opinion generally diffused, but it was taken up by officers of our own service and others interested in the science of gun construction. So it was up-hill work with this metal for some years afterwards, to convince such doubters that there was taking place a vast improvement in quality, gained by knowledge and experience in its manufacture. Until finally, with more knowledge of the quality of the metal required for guns, all must now turn to steel, to get a metal that can be readily made to exhibit the best combination of the qualities required.

The two remaining guns recommended by the Board in 1872, were the 9-inch Sutcliff and the 12-inch Thompson breech-loading rifles. Both of these guns were made by the Government and

tested at Sandy Hook, but the first was fired in all only twenty-six, and the later, two rounds. Following this, in 1876, the pieces were sent to Philadelphia for exhibition at the Centennial, after which they were again returned to Sandy Hook. But, thereafter, no experiments were made by reason, as it appears, that no specific appropriations for the purpose were made by Congress. In each of the succeeding years, 1878, 1879 and 1880, the Chief of Ordnance recommended without avail an appropriation of $117,600 for the tests of these guns, including the Woodbridge 10-inch rifle, the Lyman multi-charge gun, and the Mann 8-inch B. L. rifle.

SUTCLIFF 9-INCH B. L. RIFLE.

In general construction this gun consists of a cast-iron body with a comparatively thick steel tube inserted from the rear and terminating at the front of the block; whilst in rear of the block and its slot, the cast-iron body is bored and threaded to receive a movable hollow screw-sleeve, which supports the block from the rear and through which the charge is inserted. The breech-block is made in the form of a disk, and is moved in its slot by rotating the sleeve. A Broadwell ring is used as a gas check. It was the intention in making this gun, to provide both for a test of the breech mechanism and the principle of steel-lining in a cast-iron body, and the dimensions given to the parts were considered sufficient to enable the bore to be enlarged to ten inches, after firing 250 rounds as a 9-inch gun. The tube was inserted with a slight play in the casing and was forced home by hydraulic pressure. Shoulders on the exterior of the tube prevent its forward movement, and it is also held by a screw muzzle-collar and by a couple of securing pins through the casing. A powder chamber 0.3 inches larger in diameter than the bore is provided, and its axis is eccentric with that of the bore, being placed 0.05 of an inch above it. In the twenty-six rounds fired, the heaviest charge contained forty-five pounds of powder and 250 pounds projectile. The maximum pressure observed was 29,250 pounds per square inch. The test gave no measure of the strength of the system of tubing, owing to the limited number of rounds fired and the surplus of strength for a 9-inch gun; but in any event the breech mechanism constitutes its most interesting features. It is difficult to explain such features without the aid of a drawing, but an idea may be had of the slot in which the block moves by

supposing one side of the Krupp slot left solid, and the opening made in one side only. The block which moves in this slot is a disk of steel—in this gun 12.4 inches thick, or say $1\frac{1}{2}$ calibres—which is moved by means of a steel pin connecting with the movable screw-sleeve operated from the outside rear. The pin is set in the block near its periphery and is free to revolve in its socket in the sleeve. In giving the sleeve a half revolution the pin is carried around and the block is constrained to move in the slot, to open or close the breech, partly by rolling and partly by sliding. An obturator plate similar to the Krupp is imbedded in the front of the block to support the Broadwell ring. The block is pierced with an axial vent. This breech mechanism has few parts and the motions are simple. It embodies the disadvantage of having an unequal section of metal through the breech just in rear of the place of maximum tangential strain, and where the longitudinal strain is most felt, but to a less degree perhaps than the Krupp mechanism. It also occupies a greater length of bore-space than the French system. It might be claimed to have an advantage over this last, for longitudinal strength, because of the continuous thread of the breech-screw, but the diameter of this screw must be made so great as to considerably reduce the cross-section of metal that resists the longitudinal strain. But the difficulty found in operating it under fire and that which appears to be the weakest point, is the inadequacy of the arrangement for controlling and moving the block. The stud pin which forms the only connection between the block and the breech-sleeve is subject to severe strains, and in a few rounds fired it occurred that this pin became bent and the block was operated with difficulty.

THOMPSON 12-INCH B. L. RIFLE.

This gun is made of a cast-iron body, of the usual Rodman model, in which is inserted, under a slight shrinkage, a thin steel lining tube that extends through the bore and is secured by a screw-thread at the breech end. It was incomplete when received at the proving ground and in this condition was fired two rounds before being sent to Philadelphia in 1876, and thereafter, for reasons already stated, the test was not resumed. In the form of slot for breech block it resembles the Sutcliff gun. The face of the block when closed abuts directly against the rear end of the tube and closes the opening. The block is circular in cross-section and is rolled laterally in the horizontal slot to open or

close the breech. It is fitted with cogs which engage in a toothed rack laid in the bottom of the slot. Power is applied by means of a lever attached to a shaft or spindle which is secured to the centre of the block and extends through the breech to the rear, and is there geared to work in a rack. On applying power the spindle and block revolve together and the spindle traverses a horizontal slot cut throughout the length of the breech along one side of the loading channel. The charge is inserted through the loading channel which forms a prolongation of the bore to the rear. The back of the block is faced with a cam, which, in the act of closing the breech, comes in contact with a corresponding cam on the rear face of the slot, by means of which the block is forced forward until its beveled face is in close contact with the end of the tube fitted to receive it—thus closing the breech. When closed, the block is supported in rear about its circumference, except across the opening made for traversing the spindle. The width of the cam bearing round the block is 1.5-inches.

When the gun was tried no means were provided for locking the block in position when closed, nor was there any provision for a gas-check or vent proper. It was the intention of the inventor to use centre-primed metallic cartridge cases, to be discharged by a firing pan passed through the centre of the spindle and block. There are no features about this mechanism, I believe, which call for any special commendation in the light of present knowledge. The attempt to use a metallic case for a gas-check was subsequently tried in the Yates 8-inch B. L. rifle, with very poor success. The difficulty of holding the block up to place in the Thompson gun would be a serious one, and it might be anticipated that the bearing surface of the block in rear would prove insufficient, and the longitudinal strain to cause disruption of the breech, would be besides wholly thrown upon one angle in the slot.

FIELD GUNS.

During the period 1873 to 1882, trials were also made at Sandy Hook with breech-loading field guns, and the Dean 3.5 mandrelled bronze gun. The Dean gun was procured in 1877. It was subjected to a firing test of fifty rounds which, so far as it went, proved the excellent quality of the material, but it was a muzzle-loading gun, made after a design already out of date, and gave inferior ballistic results. The introduction of steel, in new constructions, operated against the extension of the

system. This system of manufacture has been tried in Russia, Italy, and especially in Austria, where, under General Uchatius' earnest supervision, it was finally introduced for field and the lighter siege guns, but was not successful in application to heavier guns.

The three systems of field guns principally tested were the Sutcliff 3-inch, Moffat 3.07-inch, and the converted 3.2-inch field gun with Krupp mechanism, made on the plans of the Constructor of Ordnance.

The Sutcliff B. L. field gun was made by converting a 3-inch wrought-iron rifle, the breech mechanism being in all essential respects like that of the 9-inch gun. The trial gun was received at the proving ground in 1876; it was fired 53 rounds, an average charge being 1¼ pounds of powder and 10 pounds projectile, which gave a velocity of 1109 f. s. The reports state that, so far as tested, the working of the breech mechanism was satisfactory.

The Moffat B. L. gun was brought out in 1873. The body is of steel, made from a solid piece. The breech block, as in the Mann gun, is secured by a strap or breeching pivoted on the trunnions; and each arm of the strap is supported by locking into lugs on either side of the breech of the gun. The strap rests upon the head of the elevating screw, and the breech is raised clear of it for loading by means of a lever pivoted on the screw. The block is hinged to the under side of the breech, and has a conical face which fits closely in the breech. The rear of the block is wedge-shaped, and in closing is pressed into its seat by contact with the cross-head of the strap. When the breech of the gun is raised for loading the block revolves backward and rests upon the strap. This gun was fired 175 rounds, and gave a velocity of 1124 f. s. with a charge of 1¼ pounds of powder and 10¼ pounds projectile.

The converted 3.2-inch B. L. field gun, Krupp mechanism, was first proposed in 1878, and trials were made with a gun of 3.17-inch calibre, in 1879. Subsequently the calibre was increased, and the 3.2-inch was decided upon. The conversion consists in cutting off the breech of a 3-inch wrought muzzle-loading rifle near the bottom of the bore, and screwing in from the rear a steel breech receiver through which the bore is prolonged. The breech block is supported in the breech receiver, which also extends forward some sixteen inches within the wrought-iron body, inclosing the chamber and forming the rear portion of the bore.

The breech block is of the Krupp pattern made in this country, and the Broadwell ring is used for a gas-check. By chambering, the power of this gun was much increased over that previously obtained with guns of like calibre, and as its trials were satisfactory, the gun was provisionally adopted for trial in service. A few have been made and issued for service and are still in use. In trials reported, in 1883, the first gun shows a record of 849 rounds, as far as tested. In prolonged firing the principal difficulty was found with the gas-check, which became scored, and allowed the escape of gas. With a new gas-check 275 rounds were fired without material injury, and it was concluded that one check would be good for about 300 rounds. The powder charge is three pounds, and the solid shot weighs twelve pounds. With this charge the pressure averages 25,633 pounds, and the muzzle-velocity is 1548 f. s. The range at 20° elevation is 5879 yards, or 3.34 miles; at 15°, 4978 yards; at 10°, 3986 yards, and at 5°, 2508 yards. The gun weighs 826 pounds, and the muzzle energy of shot per pound of piece is 541.2 foot tons.

To sum up the results of the ten years ending in 1882, which were devoted to the development of guns recommended by the Board of 1872 (appointed by Act of Congress): The Woodbridge brazed, wire-wound gun, and the Hitchcock gun, were thoroughly tried with results already mentioned—the former presenting great difficulties in manufacture, and failing under proof, and the latter failing in manufacture. The Sutcliff 9-inch, Thompson and Mann guns were tested to a very limited extent with results, in the case of the first two, which did not at best give any marked prospect of success; but Congress, by its refusal to appropriate money for the purpose, negatived an exhaustive trial of them. Lyman's multi-charge gun comes under the same category; however, tests already made at Reading with the same gun that was awaiting trial at this time indicate that the interests of the country did not suffer in the failure to test it further.

The successful issue of the period was the Ordnance system of converted muzzle-loading rifles whereby there was placed in service 210 8-inch rifles, each having, at a 1000 yards range, more than double the power and three times the accuracy of the 10-inch smooth-bore which it replaced, besides made strong enough by the conversion to endure fully as many, if not more rounds as a rifled gun, than the old smooth-bore would stand with its light charges. And, however poorly these rifles may now appear in

comparison with the modern gun, this much must be remembered —if a war should arise to-morrow, they are the only reliable rifles that we have available for sea-coast defense. The power of this gun to penetrate eight inches of iron armor with backing, or six inches of steel armor, at 1000 yards range makes it effective against a large proportion of the war ships of the world. It would, of course, be of little use in firing against the heavily-armored ships, but these constitute perhaps one-fourth only of the whole number of such ships.

The 11-inch rifle of the same construction was successfully tested, but was not made a service type, which was a wise course, seeing the relative disparity of this calibre to those of other countries, when it became a question whether to make these guns in quantity, and noting also the present efficiency of the 15-inch smooth-bore with its increased charge. In other words, it did not then appear to be a paying investment—and, with our present knowledge, it would appear much less so—to sacrifice a 15-inch smooth-bore to make an 11-inch muzzle-loading rifle. The converted 8-inch B. L. rifle of the same general construction, with Krupp mechanism, unchambered, and firing a charge of 35 pounds of powder was a practical success. The principal utility of the proof of this gun lay in the trial of the breech mechanism; the gun proved abundantly strong to withstand the charge which was used, but the design could not be adopted as a service pattern, because it presented the disadvantage of increased cost with no corresponding increase of power or efficiency over the muzzle-loader. The next step in the development of this system was to obtain a satisfactory increase of power for the converted breech-loaders (8 and 11-inch) by chambering to use a largely-increased charge of powder, and to extend the system to new constructions of large calibre, with increased length of bore to give high power. The first 8 and 11-inch guns failed, we may infer, because of the square angles of the slot, although the steel used in them was not of suitable quality. The second 8-inch gun, with rounded angles in the slot and the same make of steel, burst at the 127th round after enduring a series of high pressures ending with six consecutive fires, giving pressure running uniformly about 50,000 pounds and over. The inevitable conclusion from these trials was that this system of converted breech-loaders did not possess the margin of strength which would warrant its introduction in service. The extension of the system to large

calibres of new construction was abandoned, because it was impracticable to obtain a suitable quality of steel in the forms required by the design.

One lesson may at least be learned from what took place in these ten years, and that is that success in gun-making depends not upon the test and trials of different plans, however numerous, but upon a steady and persistent effort upon one system; and when, as in our own country, the sums appropriated for such purposes are small in amount this course offers the only means of reaching any degree of success whatever.

III.

THE CONCLUSIONS OF BOARDS AND COMMITTEES APPOINTED BY CONGRESS. MONEY EXPENDED FOR THE PURCHASE OF CANNON DURING TWENTY YEARS. RECENT PLANS OF GUN CONSTRUCTION. THE MULTI-CHARGE GUN. THE MANN AND THE YATES BREECH-MECHANISM. THE SLOTTED SCREW BREECH-MECHANISM.

COMING now to a later period, the course of legislation in Congress, which governs these matters, has been such as to leave all questions of policy in a state of the greatest uncertainty, and we find the War Department laboring under the most adverse circumstances in endeavoring to further the manufacture of the best type of guns recommended by the Logan Committee, or the Senate Ordnance Report of 1883.

Beginning with the appointment of the Getty Board in 1881, every year thereafter, except 1882, when the report of that board was under consideration in Congress, has been marked by the appointment of a new board pursuant to Act of Congress, until finally the subject of boards reached a period of at least temporary exhaustion, when the report of the Fortification Board was brought out in 1886. In that year, and in 1887, there was no board designated, but neither was there any fortification bill passed.

The Board on Heavy Ordnance and Projectiles, of which General Getty, an Artillery officer, was president, was appointed pursuant to the Act of Congress approved March 3, 1881, and submitted its report in May, 1882. The Gun Foundry Board was appointed pursuant to the act of March 3, 1883; the Armament Board pursuant to the act of July 5, 1884; and the Fortification Board pursuant to the act of March 3, 1885. Besides which, in the same years, we have had careful and detailed examinations and reports on the question of heavy ordnance from the Senate Committee, of which Senator Logan was chairman, appointed August 2, 1882; the Senate Select Committee on Ordnance and War

Ships, with Senator Hawley as chairman, appointed July 3, 1884; and a similar House Committee, with Mr. Randall as chairman, appointed July 6, 1884. There is also the Standing Committee of the Senate, with Senator Dolph as chairman, which has charge of matters pertaining to ordnance. The Select Committees on Ordnance and War Ships of the Senate and House completed and submitted their reports in 1886. It is not my purpose here to analyze the able reports of all these committees and boards; they contain a vast amount of valuable information upon the subject which we can only regret has been put to so little practical use, in so far as the land defenses are concerned. Of all the subjects treated in these reports (if we omit the Armament Board, which was convened for a distinct purpose apart from this question) there was one of all others upon which there is a unanimity of opinion, either explicitly expressed or directly implied, in their conclusions, namely: *That the solution of the gun question lies in the manufacture of the built-up forged steel gun, and that the industry of making forged steel for such guns should be established in this country.*

Another matter which also received general commendation was that the recommendation of the Gun Foundry Board in regard to the establishment of government factories (for the Army and Navy), with capacity to manufacture a limited number of these guns per annum, should be adopted.

But the conclusions of these committees and boards have been very useful in helping the Navy to get appropriations for this class of guns in the quantities needed for vessels in course of construction. And now that the policy of making them has been definitely inaugurated in one branch of the Government Service, it will surely be extended to the land service. It has been said that the Ordnance Department has expended millions and millions on guns and has nothing to show for it. It may be useful information then to state the fact that the total amount expended for cannon in the twenty years beginning July 1, 1866, and ending June 30, 1886, by the Ordnance Department, did not exceed one and one-half million of dollars. This does not include the amounts expended from the appropriations for *testing* experimental guns and various inventions, including dynamite, powder, projectiles, and material for service and reserve; but it does include the first cost of all the cannon procured in the twenty years, and in addition what had been expended upon those in

course of construction at the end of the period. It covers the cost of the plant erected for the Woodbridge gun, the Hitchcock gun, the money otherwise expended for those guns, and all other experimental guns, and also of the following service-cannon—318 in number—which are now in use or available for issue, viz.:

1 20-inch and 26 15-inch Rodman smooth-bores.
1 12¼-inch tubed M. L. rifle.
5 11-inch, 1 10-inch, 210 8-inch } M. L. converted rifles.
4 8-inch B. L. converted rifles.
1 12-inch M. L. rifled Howitzer.
1 8-inch B. L. steel rifle.
7 3.2-inch converted B. L. rifles.
25 3.2-inch steel B. L. rifles.
36 steel Hotchkiss B. L. Mountain guns.

This sum of money, covering twenty years' expenditure for gun making for the War Department, is just equal to the amount allowed for the completion, exclusive of armament, of one of the new steel cruisers, for which we are expected to afford harbors of refuge.

RECENT PLANS OF GUN CONSTRUCTION.

We now turn to the guns of the present period, which, for authority to make by the War Department, are the outcome of the deliberations of the Senate Ordnance Committee of 1883, from testimony taken by that committee, from plans submitted to it, and from a review of the recommendations of the Getty Board of 1881. The recommendations of this committee were embodied in the Fortification Bill of 1883. That Act authorized the continuance of the conversion of 10-inch smooth-bores into 8-inch muzzle-loading rifles, and, in addition, the trial of five different systems of gun construction and two distinct types of breech-mechanism, as follows:

1. Built-up forged-steel breech-loading rifles with slotted screw breech-closure.
2. Cast-iron (simple) breech-loading rifles with slotted screw breech-closure.
3. Combined cast-iron and steel built-up breech-loading rifles, and rifled mortars on the same system, with slotted screw breech-closure.
4. Wire-wound breech-loading rifles.
5. The multi-charge gun.
6. The Mann breech-mechanism.
7. The Yates breech-mechanism.

him to "select from the many breech-loading devices offered to the Getty Board and Committee on Ordnance two that promise the greatest success" for test at the cost of the Government.

The five systems of construction as such, based on various plans, had all, except the cast-iron rifle pure and simple, received the recommendation of the Getty Board. The simple cast-iron rifle was not recommended by the Getty Board, but was inserted in the Act of 1883, as stated: "In lieu of such of the guns the construction of which has not yet been commenced, as were provided for by the Act making appropriations for fortifications, etc., for the fiscal year ending June 30, 1881." The Government had procured the iron, and preparations had been made at the South Boston Foundry for the castings here alluded to, which were intended for the 12-inch breech-loaders, that could not be made for a lack of a proper quality of steel for breech-receivers.

Three of the systems, the built-up steel, the simple cast-iron and the multi-charge, and the two types of breech-mechanism contemplated in the Act of 1883, have been subjected to trial; another, the combined cast-iron and steel, has been submitted to partial trial only in the proof of a 12-inch muzzle-loading rifled mortar hooped with steel, whilst the rifles made on the same system are in a more or less forward state of completion, which has been arrested, for two years past, through the lack of funds to pay for them; and the remaining one, the wire-wound, is in the same category as the guns just named; work on two of these wire guns, which has been in progress at Watertown Arsenal, is stopped for lack of money.

Of the plans of guns under consideration, all those exemplifying the built-up steel, the simple cast-iron and the combined cast-iron and steel guns, were made by the Ordnance office. The plans of the wire-wound guns are due to Dr. Woodbridge. Mr. Haskell is the exponent of the multi-charge gun. The Mann and Yates breech-mechanisms are designated by the names of their designers, and these gentlemen each supervised the construction of the gun embodying his plan. All work done, and material furnished for the manufacture and test of the guns, has been at the expense of the Government, except for the multi-charge gun, which was furnished at private expense, and the costs of the tests only paid by the Government.

The trials at Sandy Hook, in 1883–84, were made with a new 6-inch gun completed at Reading, Pa., in 1883. This gun, weigh-

THE MULTI-CHARGE GUN.

The principle feature of this gun is well-known to consist in the application of the accelerating principle as applied to the action of the powder upon the projectile, and this is sought to be obtained by using a series of powder charges placed in pockets at intervals along the bore near the breech, which are intended to be ignited by the inflamed gases of the breech-charge following the passage of the projectile over the opening of each powder pocket into the bore. The breech-charge is relatively light to give a gradual impetus to the projectile which is placed immediately in front of it, and in rear of all the pockets. The mechanical difficulties in this construction are many, but two of the most important are: first, the necessity for a perfect closure of the gas escape at the base of the projectile, to prevent a premature ignition of any of the charges in the pockets: second, the difficulty of making a gun of this kind strong enough to withstand even the reduced pressures which may be obtained by an application of the principle. This last is especially important, for when we talk about safe pressures in a gun, it is of course only a relative term and applicable to the particular gun under consideration. As for instance, a pressure of 50,000 pounds has been found quite as safe for a tubed converted gun with a cast-iron body, as 27,000 pounds for the tubed multi-charge gun with a cast-iron body, since both of the guns ruptured under these pressures; only, that the converted gun stood a total of 127 rounds, and the multi-charge a total of 33 rounds, before its first failure, and of 53 rounds up to final rupture.

The brief account that I can give of this invention is taken from statements made by its proprietors before the Board of 1872 and the Getty Board, and the reports of some officers who have witnessed its test. The system was patented by A. S. Lyman, who, in conjunction with J. R. Haskell, commenced to make experiments to test the merits of his invention to have it brought into use about 1855. Of the various experiments that may have been made, we have accounts of the performance of three guns only, viz.: a 2½-inch gun tested at the Washington Navy Yard, a 6-inch gun tested at Reading, Pa., in 1870, and the 6-inch gun which was tested at Sandy Hook, in 1883-84. The most striking experiments otherwise described, were made with

The two types of breech-mechanism were selected by the Chief of Ordnance, under the requirements of the Act which directed

a so-called gun, but rather a small-arm tube, ten feet ten inches long, one-half inch calibre, giving the enormous proportions of 260 calibres length of bore. In this tube was arranged one breech charge and five additional pocket charges. The bullet was of steel, eighteen calibres in length. It is stated that with a total powder charge of 8¼ ounces, and 7¼ ounces, in the steel bullet, a penetration was obtained through twelve plates of boiler-iron bolted together; each plate was something over ⅜ of an inch, and the total thickness was 5¼ inches. This result showed a penetration of 10¼ calibres. The initial velocity of the bullet was not measured, but a computation by the engineer of the company made it 3000 f.s. Carrying the same proportions, and *assuming* corresponding results with a 9-inch gun, there would truly appear, as an advocate of the system has claimed, a penetration of 7 feet 10½-inches of iron armor, and he might have added, the gun would be 195 feet long and the projectile 13½ feet long. However, a better judgment can be formed by showing the actual results obtained with the guns constructed, as this is the only safe guide in such matters.

The 2½-inch gun at the Washington Navy Yard penetrated a target of wrought-iron plates 5 inches thick, backed by 18 inches of solid oak timber. This gave a penetration of "more than two calibres." The firing was done at point-blank range, 200 yards, with a total charge of 6¾ pounds of powder and a hardened steel projectile weighing 19¾ pounds. This gun was afterwards fired at Sandy Hook for velocity—the maximum obtained was 1929 f. s. with ten pounds of powder and eight pounds projectile.

An account is given of thirteen rounds fired from the 6-inch gun at Reading, Pa., in 1870. This gun had four accelerating pockets and a total weight of about 11,000 pounds. The initial velocity was measured for six rounds, of which the best record is 1093 f. s. To quote from Captain Prince's report of the trial which he witnessed: "the large local pressures and moderate velocities developed in this trial, where precisely an opposite state of things might reasonably have been looked for, can only be explained by supposing that the pocket charges in some cases became ignited before the projectile had passed over their *embouchures*." This is the gun, I believe, which was taken to Sandy Hook, for trial, pursuant to the recommendation of this system by the Board of 1872.

ing 25 tons, was made of a cast-iron body, lined throughout its length with a steel tube, chambered for the breech-charge, and having a length of bore equal to 46 calibres. A breech-closing mechanism enables the insertion of the projectile and breech charge from the rear, and the four powder pockets were loaded by pouring the powder into the channel connecting with each pocket from the exterior. The typical method of loading consisted in using five different kinds of powder in the separate charges, relatively slow burning in the breech-charge and increasing in fineness of granulation and quickness of burning for each successive pocket forward. In the later rounds of the proof this arrangement was modified to use two powders of the same granulation, but of different brand in the two pockets next the breech-charge.

The proof was begun with a charge of twelve pounds of powder in the breech, and the pockets empty—this round gave a velocity of 1067 f. s., with a projectile weighing 108 pounds. Working gradually up by increasing the number of pockets loaded, and the total powder charge at the same time, at the thirteenth round the full number of five charges was first used. In this round the total weight of powder was 83 pounds, and projectile 109 pounds. The pressure within the chamber and pockets reached about 20,000 pounds, and the initial velocity was 1.735 f. s. The firing was then continued with varying charges of powder and projectiles up to the 33d round, when the tube was cracked over a length of nine feet from the muzzle to a point near the foremost pocket. The pressure in these rounds varied in the different charge receptacles from a minimum of 18,000 to 29,000 pounds which was the maximum record of pressure obtained from the gauges placed in the breech, and in each of the four pockets. The highest record of *velocity* in this trial, which appears also to be the highest yet obtained from a 6-inch multi-charge gun, was 2101. f. s., obtained with a total powder charge of ninety-six pounds, and a projectile weighing 71 pounds. The gun was then strengthened by shrinking several steel bands over the chase—the only part where the form of the gun admitted the employment of this strengthening process. The proof was then continued up to the 53d round, when the cast-iron body was cracked and the piece permanently disabled. The highest pressure that the gun had to endure in the proof was an exceptional record of 31,550 pounds—an average of the pressures with full charges

being about 27,000 pounds per square inch. The best record of energy obtained during the proof, was given with a total powder charge of 116 pounds and projectile four calibres in length weighing 152 pounds, for which the velocity was 1801 f. s. and muzzle energy 3422 ft. tons.

I have no desire to pose in public as a hostile critic of the multi-charge system exemplified in the guns just mentioned, but rather the reverse, seeing the methods of attack that are used against those who honestly oppose it. A large amount of private capital has been expended in the attempts to perfect the gun and experiments with it were earnestly pursued for many years. If the principle were really valuable we should have expected in the latest model some conclusive evidence to that effect. The present status of these guns is a matter of public concern, and the conclusion which I draw from the actual results obtained, is that the principle is not valuable in the present advanced state of the art of gun construction. A higher energy and a greater penetration than the multi-charge gun has shown, is a matter of everyday record with guns using a single charge of powder, and the greater effect of the single charge gun is produced at a much less cost for original construction and for maintenance, and also with a much safer pressure in the gun. A pressure of 50,000 pounds, of which only about 70 per cent. is needed for the service of the piece, is entirely safe for a single charge steel gun, but what a multi-charge steel gun would stand is highly problematical. A comparison of cast-iron lined constructions has shown a better endurance for the single charge gun under 50,000 pounds pressure than for the multi-charge under 27,000 pounds. Probably the relative merits of steel constructions would be about the same. Most emphatically then a higher energy has not been obtained with this gun with its successive charges and with moderate and *safer* pressures than can result from any gun of the same calibre using only one charge, nor is there any ground to hope that such a result can be expected.

THE MANN BREECH-MECHANISM.

The principle involved in the Mann breech-mechanism is to accomplish a complete separation of the longitudinal from the tangential strains due to firing a gun. As illustrated in the 6.5-inch rifle, tested in 1884, it comprises a heavy breech-block supported and threaded in a transom, having no connection with the

body of the gun at the breech. The ends of the transom, which project beyond either side of the breech, are fastened in heavy side-straps that extend forward and loop over the trunnions of the gun body. The gun body, proper, is made with a tube open from end to end, and is counterpoised at the trunnion bearings in the straps. The trunnions proper, which connect the whole system with the carriage, form a part of the side straps, and these straps support the longitudinal strain due to the pressure on the breech-block. The breech is opened, or closed, by raising or lowering the breech of the gun-body which revolves about its own trunnions. The breech-block, when closed, covers the breech end of the tube and supports the gas-check ring.

The Mann breech-mechanism has been known and tried at different times for a number of years. Mr. Mann stated to the Logan Committee that in 1862 a 3-inch gun was fired at Battery Fox, Washington, D. C., 437 times under the direction of Admiral Dalghren, and that during this firing the gun was fired ninety-six times in seventy-six minutes without interruption. In the same year the Navy Department gave him an order for an 8-inch breech-loading rifle made on the same plan. This gun was completed in September, 1873. A number of trials were made with this gun by the Navy Department, and it was then turned over to the War Department. Tests were made with it by Captain Edson, of the Army Ordnance Department, at Fort Monroe Arsenal, Virginia, in 1865. He found the working of the breech-mechanism to be fairly satisfactory. This was the gun considered by the Board of 1872, and pursuant to the recommendations of that Board, and the plans of the inventor, the piece was altered in several particulars and transformed into a gun of 8.4 inches calibre. Previous to this transformation, the gun had been fired fifty times. The only tests made of the piece after this were two rounds fired at the foundry, and eleven at Sandy Hook, in 1875. This record was sufficient to induce the Chief of Ordnance to select this mechanism, under the Act of 1883, as one of the two, out of all those submitted to the Getty Board, which should be subjected to trial and test. A new gun, conforming to patents taken out by the inventor in 1882 and made under his supervision, was then procured at the cost of the Government. This gun, as already stated, was tested at Sandy Hook in 1884. The test was made under the Board for Testing Rifled Cannon, instituted as a permanent board by the Act of July 5, 1884, which

provides that hereafter all rifled cannon manufactured at the cost of the United States shall be publicly subjected to the proper test for the determination of the endurance of the same * * * and further, if such guns shall not prove satisfactory they shall not be put to use in the Government service. The history of this test is, in brief, given in the report of the board: This gun, having burst at the 24th round, its endurance was not satisfactory to the board, and hence it cannot recommend that it be put to use in the Government service. The highest recorded pressure was 27,500 pounds per square inch. The failure of the gun was occasioned by the fracture of the transom near its left tenon. This transom was made of a superior quality of Whitworth steel, and the fracture showed no defects in the metal. There was evidence during the firing that the side-straps did not hold the breech-block up to its place, as the breech of the gun-body was slightly raised from its place by the shock of discharge.

The principle of this breech mechanism appears to be a mistaken one; the longitudinal strain in a well built gun does not materially detract from the tangential strength. Some constructions, as in the case of wire guns, may require a special provision to obtain the necessary longitudinal strength, but these should form an integral part of the gun, and be solidly and firmly built into the structure. It would appear that any attempt made to separate the parts designed to withstand the two kinds of strain must either result in an essentially weak gun in one direction or the other, or else in the addition of a surplus, if not a useless amount of metal to accomplish the object sought. Certainly in a built-up gun, such as was the body of the Mann 6.5-inch rifle, there exists no reason for such a complication as the attempt to separate the two kinds of strains. The trial was, however, a distinct test of the breech-mechanism.

THE YATES BREECH-MECHANISM

Is the subject of a patent issued June 28, 1881, to Colonel Yates, a retired officer of the Army. It is novel in principle and application, and consists of a couple of concave clamps (half sections) which, when closed, embrace the breech of the gun exteriorly, and are intended to afford longitudinal support to a solid head gas-check or cartridge case of whatever nature that may be used within the breech end of the tube for the actual gas-sealing device. The gas-check ring being a distinct feature, to be oper-

ated independently of the breech-loading device, is not to be understood as forming a part of it. To understand this distinction, without intending to draw a parallel, the Yates breech-mechanism takes the place of the threaded-block alone in the slotted screw system, or the sliding-block alone in the Krupp system. A parallel cannot be drawn, because in each of the two systems named, the block forms a ready means for supporting or supplementing the gas-check and making a complete automatic breech-opening device, whilst in the Yates plan there is no connection between the gas-check and the rest of the mechanism—the breech is not opened or closed by the operation of the mechanism, but there is required, in addition, a heavy solid head gas-check, which must be placed by hand in the breech-end of the tube and removed in the same way for every round fired.

The "clamps" form a shell or envelope for the entire breech of the gun divided into two equal parts or sections which meet in a vertical plane through the axis of the gun. The front of each clamp is hinged (in common) well forward on the reinforce of the gun, and grooves or shoulders are cut circumferentially on the interior of the clamps which, when the sides are closed, hook upon corresponding shoulders cut around the reinforce of the gun and afford longitudinal support to the clamps. The shell formed by closing the clamps comes to a close bearing over the breech-end of the tube to support the gas-check. The sides open to uncover a little more than the diameter of the bore at the breech. The opening and closing is done by means of a lever attached to the under side of the breech of the gun and pins on either clamp, which work in grooves cut in the lever. When closed, the clamps are held together by an outside latch-fastening placed above the axial line of the gun. This, at least, was the original arrangement; and the axial line was occupied by a firing device intended to insert a pistol cartridge to be used in firing the charge, but the latch-fastening broke away after firing a few rounds, and was replaced by a locking disk; and a radial vent was made to be used instead of the axial vent.

The trial of a gun fitted with this mechanism was made by the board for testing rifled cannon at Sandy Hook in 1885-86. The gun, made at the cost of the Government, was an 8-inch rifle converted from a 10-inch Rodman smooth-bore. The work was done at South Boston, under the supervision of the inventor. The breech of the smooth-bore gun was shaped and bored

through, and the muzzle lengthened by screwing on a cast-iron extension piece. The whole was lined with a close-fitting steel (Nashua) tube making a chambered gun body of twenty calibres length of bore. In applying the exterior parts of the breech-mechanism to this gun, the outside of the reinforce was necessarily turned off to provide the shoulders for the support of the clamps. To complete the breech-closure, that is, to close the rear end of the bore and prevent the powder-gases from acting in and through the unsealed joint at the junction of the clamps, the inventor designed a cartridge-case of bronze, twelve inches total length with thin walls, and heavy solid base weighing 48½ pounds. This case was tapered on the outside corresponding to a seat made for it in the chamber of the gun to facilitate withdrawal. And to provide against sticking, a slot was made in the rear of the tube to catch the head of the case with a hand-extracting tool. This case was intended to be used for repeated firings, but was necessarily withdrawn after each round—the work being done by hand as a distinct operation of opening the breech.

The gun was fired, in all 312 rounds, when it burst through the body, and the breech-mechanism was destroyed by the rupture of the body. Except for the breaking of the latch in the early firings, there was no failure of the breech-loading device—but the trial developed its unsuitability as a breech-mechanism. The board pronounced the separation of the gas-check from the mechanism to be a "clumsy, inconvenient and objectionable" feature as proved by the trial. And found that the "obturation was imperfect," the gas-checks "not satisfactory" and besides, 'heavy" and "difficult to handle," and "liable to serious injury from accidental dropping or striking against objects in rapid firing." In the 312 rounds fired, eleven different forms or dimensions of gas-checks were tried and none were found satisfactory. No attempt was made by the inventor to employ a gas-check which would not require the awkward handling mentioned. As a consequence of this serious defect the Yates breech-mechanism-as applied to guns of heavy calibre, is not at present a practicable breech-closing device.

It may be added, I think, as an objectionable feature in applying this mechanism, and the same feature is even more pronounced in the Mann system, that the complete truncation of the body directly in rear of the powder-chamber whereby the maxi-

mum tangential strain is required to be supported so near the end of the gun-body, renders these systems liable to enlargement and very obnoxious deformation about the seat of the gas-check. It also introduces a weakness against tangential strain, which could only be met by a substantial increase in the strength of the breech-end over that required in the French system at least. Krupp does not strengthen his guns at this place by shrinking on an additional hoop. Again the Yates plan necessitates a trimming-down of the reinforce to get shoulders for the clamps, but he might, on the whole, still claim a margin of weight-saving sufficient to make an extra heavy gun at the breech-end.

The result of this trial of Colonel Yate's system, in a gun of 8-inch calibre, is an example of the difficulties which arise with an increase of the calibre; for I am informed that the device has been found to work well in pieces of small calibre such as yacht guns.

THE SLOTTED (INTERRUPTED) SCREW BREECH-MECHANISM.

In the breech-loading guns to be subsequently discussed, that is—in the experimental and standard types recently made, or in process of construction, after the plans of the Army Ordnance Department and the Navy Bureau of Ordnance in the United States, the system of breech-mechanism used throughout is the slotted-screw. This system owes its inception, as I believe, to Chambers' American patent of 1849, re-patented in a somewhat different form in this country by Schenkl in 1853, and used in the construction of six guns made at Boston, Mass., in 1855, for the British Government, after designs by an American named Castmann; owing to clumsiness of construction, however, these guns were not mounted.* The system was then taken up in France, and gradually developed upon a working plan. Holley speaks of it as the French system in 1864. The first model in the French marine service dates from 1860, and it became the adopted system of the land service, in the Reffye guns of 1870.† As regards the United States there was then no room for such development in the face of our (at that time) superior armament of heavy smooth-bores. The system was officially recommended for trial in our Service by the Heavy Gun Board of 1872, having

* Holley's Ordnance and Armor, page 608.

† Aide memoire for Officers of Artillery, Chap I. Paris, 1880. Gadand's "L'Artillerie de la Marine Français," 1872.

been especially brought to the attention of that board by Lieutenant Michaelis, of the Ordnance Department. That board also recommended other systems of breech-loading, including the Krupp system, the tests of which have already been noticed. The slotted-screw system is now generally used in native gun-making in France, Italy, England and the United States. The present style in France is the de Bange, but a distinctive feature of this—the mushroom-head and plastic obturator—is shown in the design of Lahitalle, which was intermediate between that of Reffye and de Bange. The details of the mechanism vary in different countries, only the main feature of the slotted-screw is preserved. Gas-check rings replace the plastic check in Italian guns, and in the Armstrong guns, and they differ in details from each other and from the de Bange mechanism. The plastic check is used in the heavier calibres of both our Army and Navy guns, but various modifications to effect improvements in the working details have been made the subject of experiment and test. Hence the term French breech-mechanism is applicable only in a general way to the various mechanisms which embody the slotted-screw, as used in the United States and elsewhere.

The Krupp breech-mechanism is, of course, extended in use to a number of foreign countries, where sales of his guns are made, and it has been adopted in manufacture in Russia. It is not my purpose here to discuss the relative merits of these two systems of breech-mechanism ; it may be doubted, indeed, if there is much room to choose between them, since both have been so thoroughly tested and proved. It may be remarked, however, that the slotted-screw system has been generally received by gun-makers, in choosing between one or the other, with more favor than the Krupp, and probably the principal reason for this is that the Krupp requires a forging of larger diameter for the block-carrying cylinder than does the slotted-screw, which may even be attached in the tube forging itself. The size of the required forgings for twelve-inch rifles, it will be recalled, and the inability of the English makers to produce them of requisite quality, was what stopped the extension of the Krupp system in our own Service. A possible reduction in the size of forging is, of course, always a desideratum, and especially so in a country where the manufacture of steel forgings is a comparatively new industry. It undoubtedly also requires the best quality of steel to carry the Krupp block, and where a cast-iron body is used, as

in some of our present constructions, the slotted screw-block is a necessary adjunct. It may be said then that we are now using the slotted-screw system because it is one of the only two that have been proved reliable and satisfactory; and of these it is the one which, on the whole, is best adapted to our requirements and resources. These remarks do not apply with the same force to small as to large calibres, but it is expedient to have a uniform system for all calibres.

IV.

CAST-IRON RIFLES. RODMAN, ATWATER AND WIARD GUNS. 12-INCH B. L. RIFLE, MODEL 1883. MERITS OF SYSTEM DISCUSSED.

I HAVE already stated that the trials of cast-iron rifles pure and simple, were practically abandoned in the United States, in 1871. That was a consequence of the terrible damning that cast-iron guns received at the hands of the Select Committee on Ordnance in 1869; and the recommendation of the Chief of Ordnance two years later, that no cast-iron rifles should be made for service, was the direct consequence of the bursting of a 12-inch Rodman cast-iron rifle at the 27th round. Up to the time when the subject was revived by the recommendation of the Logan Committee, in 1883, fourteen years had elapsed since the casting of the last cast-iron rifle, pure and simple, procured by the War Department. This gun was a 10-inch rifle made at South Boston, in 1869.

Seven muzzle-loading cast-iron Rodman rifles, viz.: 3 8-inch, 1 10-inch and 3 12-inch were procured by the War Department between 1861 and 1869—their principal dimensions, weights and qualities of metal were as follows:

Calibre of Gun.	Made at	Length of Bore in Calibres.	Thickness of Walls.	
			Over Chamber maximum.	At muzzle minimum.
			Calibres.	inches.
8 in.	Fort Pitt, 1862	15	1.5	4.1
8 in.	South Boston, 1865	17.5	2.0	4.0
8 in.	South Boston, 1865	17.5	2.0	4.0
10 in.	South Boston, 1869	15.85	1.75	5.5
12 in.	Fort Pitt, 1861	14.0	1.5	6.5
12 in.	Fort Pitt, 1868	14.0	1.5	6.5
12 in.	South Boston, 1868	14.0	1.5	6.5

Calibre of Gun.	Weight of Rifle.	Character of Rifling.	Physical Qualities of Metal.	
			Tenacity.	Density.
	Pounds.		Pounds.	
8 in.	15,996	Polygroove	30,416	7.2886
8 in.	22,160	For grooved projectile	34,625	7.2930
8 in.	22,220	Polygroove	34,505	7.2980
10 in.	40,700	Polygroove	32,600	7.3063
12 in.	52,005	Polygroove	30,480	7.2250
12 in.	52,225	Polygroove	36,744	7.2903
12 in.	51,980	Polygroove	34,166	7.2963

The 8-inch, Fort Pitt model, of 1862, had the outside lines of the 10-inch smooth-bore, giving it the same thickness of metal as the converted muzzle-loading rifles afterwards made from these guns. The two 8-inch South Boston models, of 1865, were special designs prepared by Rodman, and were of heavy proportions, having two calibres thickness of wall in the reinforce and weighing 6000 pounds more than the first model—the only compensation being an increased muzzle length of 2.5 calibres. The 10-inch rifle had a thickness of 1.75 calibres over the seat of the charge and a length of bore less than 16 calibres, dimensions which in built-up steel guns are altered to 1.16 calibres thickness for a rifle with 32 calibres length of bore. The 12-inch rifles had a thickness of 1.5 calibres over the seat of the charge and 14 calibres length of bore. The physical qualities of metal in all these guns was fully up to the standards of tenacity and density now attained, or that can be attained in cast-iron gun metal.

The proof of these guns was concluded in 1871, except for the 10-inch. The following shows their endurance:

Cal. of Gun.	Made at	Average Full Charges.		No. of rounds endured.	Trials concluded.	Remarks.
		Powder pounds.	Projectile pounds.			
8 in.	Fort Pitt, 1862	15	150	1047	1865	Gun burst.
8 in.	South Boston, 1865	15	150	80	1866	Gun burst.
8 in.	South Boston, 1865	15	150	845	1870	Firing suspended.
10 in.	South Boston, 1869	40	300	70	1875	Gun burst.
12 in.	Fort Pitt, 1861	55	500	472	1869	Gun burst.
12 in.	Fort Pitt, 1868	60	600	27	1871	Gun burst.
12 in.	South Boston, 1868	64	624	2	1868	Firing suspended.

The maximum powder charge, fired from the 12-inch rifles, was 70 pounds. Some projectiles of 675 pounds weight were also fired, and a few of 700 pounds; but the charges given in the table were rather above than below the average and are absurdly small in comparison with those of the present day. The second 8-inch gun on the list was rifled with five lands, separated by broad grooves, and the projectile was grooved to take the lands. The

projectiles used in the remainder were fitted with soft metal sabots, chiefly of Parrott, Dyer and Dana patterns. These projectiles were the best procurable, and the trials were conducted with care—certainly with a strong desire on the part of the proof officers to make the best of the guns.

The pressures recorded to have been endured in some of the rounds fired, exceeding largely as they do the amount due to the explosion of a charge in its own space, are something remarkable in their way, and can only be attributed to defective methods of measurement. Here we find, for instance, two consecutive rounds fired from an 8-inch gun on the same day, and with precisely similar charges, gave: one, a pressure of 90,000 pounds with 1154 feet velocity, and the next 23,000 pounds pressure with 1044 feet velocity. In the records of these pressures we find figures of 150,000 and even 240,000. Some of the pressures were measured with outside pressure-gauges, and the result of balloting of the interior pressure-gauge in producing very erroneous measurements was not appreciated. In 1881 Captain C. S. Smith tried the experiment of dropping the Rodman pressure-gauge complete from the balcony of the Western Union tower at Sandy Hook. The housing, containing the knife, etc., was designedly dropped upon a stone at the bottom of the tower. The height was such as to make the velocity of fall 63 f. s. Even with this small velocity, the cuts made, on striking, corresponded in one trial to 46,000 pounds, and in the second to 35,500 pounds of pressure (page 124—Report Chief of Ordnance, 1882). Noble and Able's experiments give a pressure of about 94,000 pounds per square inch for a charge of powder exploded in a rigid envelope and completely filling its space. The action in the chamber of a gun can never equal that in a rigidly enclosed space, and the old theory that high pressures would be produced in a gun fired with a projectile not pushed home is entirely exploded by the beneficial results obtained from air-spacing.

I am aware that the bursting of the guns has been attributed to the breaking-up of the projectiles, wedging of bands, uncertain powders and other causes which suited the interests of those who propounded these reasons, but I believe the true reason to lie in the frailty of the guns themselves. In the 8-inch steel rifle, now at Sandy Hook, for example, on two or more occasions, shot weighing about 300 pounds have been broken in the bore by the

shock of discharge; yet, in these cases, neither was there any marked increase of pressure, nor was the gun in the least injured. And again, in the trials at Annapolis, two loaded shells have burst within the muzzle of the new steel guns without detriment to the guns.

Another 12-inch cast-iron rifle, tried in 1867, was the Atwater rifle. In this gun some of the lands were removed near the muzzle to decrease the friction of the projectile, and to illustrate some other ideas of the inventor. The gun burst at the thirtieth fire, the average full charge used being: powder 55 pounds, and projectile 525 pounds. And there was also Mr. Norman Wiard's gun, generally known as the "cart-wheel" gun, which burst at the first round.

As an illustration of what cast-iron rifles will stand when *badly* treated, we may extract the four of this class which were included in Wiard's somewhat notorious experiments at Nut Island 1873–75.

Nature of Gun.		Charge.		Projectile.		No. of Rounds fired.	Remarks.
		Kind of powder.	Weight	Kinds.	Weight.		
15-in.	Wiard rifle, new gun	Oriental mammoth	50 / 140	Wiard conical	453	19	Gun burst
15-in.	Navy Wiard rifle converted from a Navy 15-inch S. B.	do	50 / 180	Wiard conical and sub-calibre	492	2	Gun burst
15-in.	Wiard rifle converted from 15-in. Wiard S. B. No. 1.	Oriental hexagonal	55 / 70 / 100	Spherical and Wiard mitten	450 / 529.5	7	Gun burst
11-in.	Wiard rifle, new gun	Oriental mammoth, Oriental rifle and Bickford rifle	50 / 100	Wiard conical copper veneered	260	5	Gun burst

The Wiard rifles are generally admitted to have been destroyed by the use of excessive charges and bad projectiles, yet the charges he used bear no comparison with those now required to be used in steel guns.

We have now brought the record of endurance of all the larger calibres of cast-iron rifles, pure and simple, which were tested, up to 1883. I could not, if I would, enter into the details of the experiments; that there may have been mitigating causes for some of the failures one would be rash to deny; but the gen-

eral merit of a system is to be judged by its endurance under fire. And there are enough examples, not only of miscellaneous cast-iron rifles, but also of those cast on the Rodman plan, in the preceding records to enable any one to decide that cast-iron rifles, pure and simple, have shown a very unstable quality, judged by their own day and generation. The supposition is not only reasonable, but it is undeniable that the Rodman rifles were tested with due exercise of care, nor was there any greater variety of charging than was demanded by the period to which they belong. This has always been a necessary accompaniment of the trial of experimental guns, and is a very marked feature in the experiments of the present day. Of the six Rodman rifles proved for endurance, as stated, three bore a good record and three a very poor record. The simple conclusion from the trials of the period is, that cast-iron rifles, pure and slmple, were proved to be distinctly unreliable.

12-INCH BREECH-LOADING CAST-IRON RIFLE, MODEL 1883.

The design of this gun was prepared in the Office of the Chief of Ordnance in common with all those representing the combined cast-iron and steel guns, and the built-up all-steel guns authorized by the Act of 1883.

The gun is a 12-inch breech-loading rifle, weighing 54 tons of 2000 pounds each, 30 feet total length, 4⅔ feet (56 inches) across the thickest part of the reinforce, and 24 inches across the muzzle. The exterior has the curved outline of the Rodman model, with the thickness of the wall decreasing towards the muzzle, and proportioned to the powder pressure to be withstood in the different sections of the bore. The maximum thickness of the wall surrounding the chamber is 21¼ inches or a little over 1½ calibres, expressed in terms of the diameter of the chamber; the thickness over the seat of the shot is also about 21 inches or 1¾ calibres, and at the muzzle 6 inches or ½ calibre. The bore is 28 feet or 28 calibres in length, of which the powder chamber, 13.5 inches in diameter, occupies nearly 5½ calibres; and the rifling consists of 60 lands and grooves 0.c6 of an inch in depth, with a twist increasing from one turn in 135 calibres at the origin, to a uniform twist of one turn in 40 calibres, which covers a length of 33 inches next the muzzle. The full charge is 265 pounds of brown prismatic powder (density of loading 0.84*) and

* "Density of loading" is the density of the products of combustion of the

a projectile 3 calibres in length weighing 800 pounds. The breech mechanism is the slotted screw system, and the steel block is held in a steel sleeve screwed into the cast-iron breech of the gun to the depth of the block recess. Excepting the parts of the breech mechanism and this sleeve, the gun is wholly of cast-iron and is in one piece, cast with a core on the Rodman plan and cooled from the interior to produce initial tension.

The gun was made under the supervision of the Ordnance Department, by contract with the South Boston Iron Works. Eight months were occupied by the contractors in preparing for and making the casting, and eighteen months in all in finishing the gun. The casting was made breech end up, with a riser of the full diameter seven feet long. Initial tension rings taken from the breech, and from the muzzle, and cut through on a radius in the usual manner, gave values of initial tension equalling 15,750 pounds for the breech end, and 3500 pounds for the muzzle end.

The firing tests were conducted at Sandy Hook, before the Board for testing rifled cannon. The report of that board upon tests made to date, will be found on page 113, Report of the Chief of Ordnance, 1886. In all 137 rounds have been fired:

(One each)	3,	powder	charge	100, 200, 230	pounds,	projectile	700	lbs.
	6,	"	"	150	"	"	700	"
	2,	"	"	225	"	"	700	"
	2,	"	"	245	"	"	700	"
	1,	"	"	245	"	"	800	"
	3,	"	"	265	"	"	700	"
	41,	"	"	265	"	"	750	"
	79,	"	"	265	"	"	800	"

Of these, 123 rounds were with full charges of powder, and 79 with full charges of powder and projectile. The average pressure with the full charges, obtained by 100 observations (two pressure gauges being sometimes used with one charge) was 28,000 pounds per square inch, and a fair deduction from the test places the velocity to be obtained, with full charges, at 1750 f. s. This is dependent, however, upon the use of the most suitable powder, the making of which is known to be a very difficult operation. The single full charge fired with German powder,

powder charge, when expanded to fill the powder chamber, referred to water at a standard temperature and density as unity. Its value is expressed by the quotient:

$$\text{Density of loading} = \frac{\text{Weight of Charge expressed in pounds.}}{62.5 \times \text{Volume of chamber space expressed in cubic feet.}}$$

gave a velocity of but 1710 feet with 31,400 pounds pressure. The best results were obtained with Du Pont's N. V. powder, of which five lots made at different times were tested, and gave variations (for full charges) from 1690 f. s. with 25,325 pounds pressure to 1809 f. s. with 34,000 pounds pressure. This last was the highest pressure to which the gun was subjected in the test, excepting one round, in which, when the pressure-gauge was dislodged, there was indicated a pressure of 47,250 pounds, which is not considered reliable. Taking the average result—charge 265 pounds, projectile 800 pounds, pressure 28,000 pounds, and muzzle velocity 1750 feet—we find that the power of this gun is represented by a muzzle energy of 17,000 feet tons nearly.

The erosion of the bore became marked before the 51st round to such an extent "as to make star-gauging very difficult." At the 96th round, the erosions became pronounced, and increased rapidly towards the end of the test, when they became so serious as to lead the board to conclude that it would be unsafe to continue the firing with the gun, but it was thought that its life could be prolonged by the introduction of a steel lining. The star gauging, which appears to have been performed under difficulties, shows a general enlargement of something over one-tenth of an inch near the bottom of the rifling and thence decreasing quite uniformly to an inappreciable quantity at the muzzle. In the chamber the maximum general enlargement appears to be about 0.025 of an inch. It is difficult to give a clear idea of the extent of the erosions in this gun, especially as to their depth. The three most prominent gutterings are 5½, 10½, and 4½ inches in length, running nearly parallel to the axis of the gun and distributed at the top and right side of the bore about the front slope of the powder and running into the shot chamber. The impressions indicate flared openings having a depth of about 0.15 of an inch, but cannot show the depths of the fine extremities of the cracks.

Before drawing our conclusions from this new addition to the list of cast-iron rifles that have been proved and tested, there should be several points considered in reference to current methods of manufacture and changed conditions of service due to the introduction of slow burning powder. It is claimed :

1. That the metal now made is better than ever before;

2. That ability to make a casting with the core extending through the portion to be used for the gun body, and casting

breech up, removes all the objectionable strains incident to Rodman castings of muzzle-loading smooth-bores and makes a gun with the best condition of metal throughout;

3. That castings of any desired size and length can be made to give as high a power to cast-iron as to steel guns;

4. That existing facilities for manufacture or means ready at hand to be applied, permit the prompt manufacture of a large number of cast-iron pieces at once—figures variously placed at something like 100 rifled-mortars and twelve to fifteen 12-inch rifles per year;

5. That the introduction of slow burning powders has made the use of cast-iron rifles safe, reliable and economical.

The claim for superior quality of metal has no foundation in fact, as may be made apparant to any one who will acquaint themselves with the tests of metal made when the manufacture of cast-iron guns was a large and extensive business, and the tests of the six large castings made within the last few years.

The extension of the core barrel through the gun body, does not remove any objections heretofore existing to the Rodman method of casting; first, because the heavy solid breech in the muzzle-loading guns afforded an assistance not counterbalanced by the local strains occurring at the junction of the bore and base; and second, because the principal objections taken to the Rodman method are not with reference to the strains located at this junction, but to those located along the barrel, where the results of the method are so uncertain. The method of casting the breech up has many objectionable features, which, probably, counterbalance any gain due to this method, but in this connection, I may mention two circumstances: A reason for introducing this method here, was because the Italians were using it, yet we are informed now that it has been abandoned in Italy, because it does not give sound metal in the breech, where the greatest strength of the gun is required. And the third casting attempted at South Boston for the 12-inch tubed cast-iron rifle, made in this way, split longitudinally while still in the pit.

The limits of size and length of casting appear to have been about reached in those made for the twelve-inch rifles which required a weight of about 108 tons of metal and a casting some forty feet in length in the rough; nor are existing facilities for manufacture such as would enable any considerable number of cast-iron rifles to be finished before we could, with home facilities, inaugurate a

steady output of built-up steel guns. The only facilities existing at present in this country, for making long and heavy gun castings are to be found at the South Boston Iron Works. What has been done there is shown by the following record of the time required to turn out six castings recently procured from that company, all requiring rough finishing only except the first on the list:

No.	Nature of Casting.	Date of Order.	Date of Casting.	Date of Completion.	Remarks.
1	12-inch Cast-iron rifle, simple.	Sept. 24, 1883.	May 6, 1884.	April 1, 1885.	Cast breech up with riser at breech 7 feet long.
2	Body for 12-inch. tubed rifle :				
	1st Casting,	Sept. 24, 1883.	July 9, 1884.	....	Flask gave way and metal deposited in bottom of pit.
	2d Casting,	....	Dec. 23, 1884.	....	Cast breech down, lower portion of flask surrounded by dry brick wall packed around with sand in pit. Casting broke across in several places in lathe.
	3d Casting,	....	Oct. 16, 1885.	....	Cast breech up and ruptured longitudinally in pit.
	4th Casting,	...	Apr. 5, 1886.	*	Cast breech up. Apparently sound casting.
3	Body for 12-inch hooped and tubed rifle.	Sept. 24, 1883.	Oct. 31, 1884.	Mar. 31, 1885.	Cast breech down with riser at muzzle 18-inches long.
4	Body for 10-inch wire-wrapped rifle.	Sept. 24, 1883.	Mar. 28, 1884.	Sept. 1, 1884.	
	MORTARS.				
5	Body for 12-inch M. L. rifled mortar.	Sept. 24, 1883.	Mar. 1, 1884.	April 29. 1884.	Casting delayed in procuring proper grade of iron and making trial cylinders for test.
6	Body for 12-inch B. L. rifled mortar.	May 15, 1886.	July 30, 1886.	Sept. 30, 1886.	

The simple cast-iron rifle, with which no accident occurred, was eight months in casting, and eighteen in finishing. And the five castings ordered, September 24, 1883, were not all made at the expiration of two years and six months. The founders certainly had very hard luck with the casting for one gun, which was only made at the fourth trial, and my purpose in calling attention to these matters is simply to show the time that has actually been occupied in such work, and the risk and difficulties which attend an attempt to make heavy cast-iron rifles. The West Point Foundry could undertake the casting of the short bodies required

*Not completed June 20, 1886, when contract expired by limitation.

for the hooped mortars, but with this exception I believe no other establishment than the South Boston Iron Works, has at present any proper facilities for the work. The hooping of the mortars with steel, will delay the output but little, and will give what has been proved to be a suitably strong construction. That 12-inch cast-iron rifles may even be cast as long as may be required for modern usage, is much to be doubted in view of the experience quoted, but the added length would not give the *power* of steel guns because of the limitations of pressure imposed upon the cast-iron. Again, to increase the length of a cast-iron gun, entails a large increase of the weight and cost. Noting that in 1865, when General Rodman, in revising the model of his 8-inch cast-iron rifle, of 1862, imposed an additional weight of 6000 pounds to gain 2.5 calibres length of bore.

That the introduction of slow burning powders has made it safe to use cast-iron rifles, is doubtful, and besides is only half stating the question, they may be safe if the pressures are kept low enough, but with a pressure as high as 28,000 pounds produced by a slow burning powder, their endurance would be an uncertain factor. This pressure would work the metal well up to the point of rupture, while in steel guns, the work of the metal is within its elastic limit, and less than half its limit of rupture. The new 12-inch cast-iron rifle has withstood an average pressure of 28,000 pounds, including a number of somewhat higher pressures, for a sufficient number of rounds to demonstrate its ability to withstand such pressures, and to entitle it to be classed as a safe medium-power gun for the calibre. This much must be conceded, and it may be anticipated that equally good guns can be reproduced, but past experience of the uncertain strength of cast-iron rifles does not warrant the assumption that it would be safe to count upon such a result as a constant product of manufacture. In addition to this the slow burning powder is very erosive in its action, and of all the metals that might be used to form the bore of a gun, cast-iron is probably the most easily eroded. We have a good example of this effect in the 12-inch cast-iron rifle which began to show marked erosion about the 50th round, whilst the 8-inch steel gun shows none after 100 rounds.

A business-like view of the problem,and it has been sufficiently investigated by both figures and firings, will show that a built-up forged steel gun, giving 17,000 foot-tons muzzle-energy at each round, is a cheaper investment than this 12-inch cast-iron rifle

giving the same energy ; that is, the greater endurance of the steel gun will enable it to continue to deliver such shots enough longer than the cast-iron gun to more than make up the difference in the original cost of the guns. And beyond this, the difference of cost is all in favor of the much lighter piece—the steel gun—for transportation, handling and emplacement. This, in itself, is enough to establish the superiority of the steel gun, but it is not the most important consideration—which is, comparatively speaking, that *the steel gun is safe and the cast-iron gun is unsafe.* It is not necessary to go abroad for a confirmation of this statement ; it can rest upon a comparison of the records of cast-iron and built-up steel rifles made at home. It is good confirmation, however, to know that the practice of the rest of the world proves the same thing.

The question whether cast-iron rifles shall be or shall not be made, rests with Congress. If they are to be made let them be ordered at once in the quantities determined upon, for there is certainly no need for further experiments in this line. Let us sincerely hope, however, that any action taken for their procurement will not interfere with equally prompt action towards procuring a full supply of built-up forged steel guns ; to fail, in this respect, would, in my humble opinion, be the poorest sort of economy.

The ability which the officers of the Ordnance Department have shown in designing so powerful a cast-iron rifle as the one lately proved is an earnest of their desire and capacity to carry out whatever Congress may direct. Had the 12-inch cast-iron rifle been made after a design presented to the Logan Committee, that was, to fire 150 pounds of powder with 700-pound shot and give a muzzle-energy of but 10,000 foot-tons instead of the 17,000 foot-tons procured in the design actually used—but little interest would attach to a discussion of its merits here or elsewhere.

V.

COMBINED CAST-IRON AND STEEL GUNS. RIFLED MORTARS. BREECH-LOADING RIFLES. WIRE GUNS.

INCLUDING the rifled mortars, there are three different types of this construction in hand at the present time, viz.: A 12-inch breech-loading rifle, mainly of cast-iron, but lined with a steel tube inserted from the rear, and forming about one-half the length of the bore; a 12-inch breech-loading rifle, with cast-iron body, strongly reinforced by a double row of steel hooping extending from the breech to a distance forward of the trunnions—the trunnions themselves forming part of one of the hoops—and a steel tube lining, as in the first gun; and two 12-inch rifled mortars alike in general construction, but one is muzzle-loading and the other breech-loading.

12-INCH RIFLED MORTARS, MUZZLE AND BREECH-LOADING.

These are short, rifled pieces intended for high-angled fire, and especially adapted for the defense of sea-ports. They throw a very heavy, elongated shell, containing a large bursting charge, to a distance of five miles with facility. The weight of shell is from 610 to 625 pounds, and its fall is sufficient to pierce about eight inches of armor. In the Russian-Turkish War a 6-inch mortar firing from shore disabled two iron-clads.

The arrangement of the pieces on shore will be made in groups of sixteen, as is proposed, placed in sunken batteries, and so trained that any desired number of the pieces in the battery can be fired in the same line of direction against a single ship. The most serious question raised respecting the employment of rifled mortar fire has been in regard to its accuracy. Their employment in groups will do much to overcome this difficulty by greatly increasing the chances of hitting, and the problem of getting a very good degree of accuracy from a single piece is one that the gun-makers will not allow to remain unsolved. Its solution seems to lie in the use of breech-loading pieces, and we have just commenced the proof of a mortar of this kind at Sandy Hook which promises the best results.

The first experimental rifled-mortar—12-inch muzzle-loading—was completed in 1884, and proved 1885-86 by the board for testing rifled cannon. The reasons leading to the adoption of the muzzle-loader for the first experimental type were because it was then thought that the old method of loading from the muzzle would be, on the whole, best adapted to such short pieces as combining simplicity and cheapness, together with less care and attention required in service, as compared with the breech-loader. This piece has been fired 403 rounds, and is considered amply strong for service. A range of 8260 yards (540 yards short of five miles) was obtained with this muzzle-loading mortar, firing a charge of fifty-two pounds of powder and 610 pounds projectile at an elevation of 45°, the flight being good and 41½ seconds in duration. Examples of the accuracy of fire obtained with full and half charges at different angles of elevation, are given in the table herewith:

Powder Charge.	Elevation.	No. of rounds.	Mean range.	Probability of striking vessel 330' long by 60' broad.	
				Vessel normal to plane of fire.	With keel lying in plane of fire.
Pounds.	Degrees.		Yards.	Per cent.	Per cent.
26	28	5	3427	35.3	98.75
26	28	10	3490	38.0	99.
26	60	5	3321	16.5	66.6
26	60	8	3260	13.	44.04
52	28	4	6935	18.	61.66
52	28	10	7142	12.5	41.32

The best record of accuracy given is a target of ten shots, range 3490 yards, showing a percentage of 99 hits for 100 shots on the deck of a vessel 330 feet long and 60 feet wide, lying with keel in the plane of fire, and 38 with the vessel lying normal to the plane of fire. And again at 7000 yards range, for a target of four shots, the percentage of hits was sixty-two for the first position of the vessel and eighteen for the second position. It was found necessary, in the firing, to use sabots—the Arrick pattern was found to be the best—prepared with care to give a certain degree of sensitiveness, and there also appeared some advantages in using them of different degrees of sensitiveness for full and half charges. These defects of material required for service, together with the generally unsatisfactory degree of accuracy and lack of uniform steadiness in the flight of the shell, led the Department to manufacture a breech-loading mortar, which, on firing

for the first time a few days since,* gave very satisfactory results. With a powder charge of sixty-five pounds, and projectiles 625 pounds, the measured range was 9,385 yards or 5 1-3 miles. Nine preliminary rounds were fired, and the flight of the projectiles was true and clean.

In general design these mortars show a short rifled-piece of about nine calibres length of bore. The muzzle-loading mortar weighs 13 1-2 tons, and the breech-loader is 3-4 of a ton heavier. The latter is fitted with the slotted screw-block and breech-mechanism embodying a new and special design of retracting gear. In general construction the two pieces are nearly alike. The principal part is a cast-iron body, which forms about two-thirds of the whole weight. On the outside of this two rows of steel hoops are shrunk on, extending from the breech forward, over about two-thirds of the length of the piece. The trunnions are forged as part of one of the steel hoops, which is shrunk on in the same way as the others. Preparatory to making the first mortar an experimental compound cylinder—a counterpart of the body of mortar around the chamber—was made by shrinking two of the lot of hoops upon a cylinder of the iron for the purpose of testing the metals and verifying the shrinkages computed for the construction of the mortar itself. In this case, as in several other similar ones tried with the different types of guns—combined cast-iron and steel, cast-iron wire-wrapped and all-steel guns—the results of these experimental constructions confirmed, in a highly satisfactory manner, the results anticipated by theory and the application of standard formulas.

These rifled-mortars are apparently made very heavy in pro portion to their length. The necessity for this arises from the heavy weight of projectile used, and because they are also subjected to a pressure which may easily reach 30,000 pounds per square inch, for it is necessary to use a relatively quick burning powder. The ratio of weight of projectile is only 1 to 50. Cast-iron is a cheap metal, and, if properly strengthened, appears well adapted to use in these pieces to make up the weight. A number of persons, actuated generally no doubt by good motives, but principally, as I must assume, because they have not carefully examined into the question, have wished to make these mortars of cast-iron alone. The reason why it is not best to do this is

* In this instance and in what follows, it should be remembered that this chapter was written in 1887. Ed.

THE 12-INCH B. L. MORTAR,

MOUNTED ON THE "EASTON & ANDERSON" CARRIAGE.

because the simple cast-iron would give no assurance of safety in the service of the piece. With the pressures used in these pieces, to repeat what has been said before, the cast-iron would be strained to near its limit of rupture. By shrinking on the two rows of hoops—one row, unless the hoops were very heavy, would not be sufficient—the strain upon the cast-iron, when the piece is fired, is reduced to somewhat less than one-half of what it would be if there were no hoops. The hoops, therefore, are shrunk on to give such a factor of safety as all structures demand, and none need this factor of safety more than do guns. Added to this the certainty of good metal in the hoops surrounding the cast-iron where the strain is greatest relieves a constant source of anxiety regarding the unsoundness of heavy cast-iron castings. We know that the hoops will hold, and that their presence will make up for a greater or less degree of imperfection in the cast-iron. The strength of these mortars based upon strains that lie within the elastic limit of the steel hoops, and about equal, for the cast-iron, to those which fail to produce an appreciable permanent set of the metal, is nearly 27,000 pounds per square inch. That is to say, the *elastic* strength of the mortar, banded with two rows of hoops, just about equals the average strain anticipated in service.

12-INCH BREECH-LOADING RIFLES.

Neither of the large rifled-guns of this system have yet been delivered, as has already been noted. The tubed-gun has reached the stage preparatory to the insertion of the tube in the cast-iron body, and the hooped and tubed-gun is completed, but cannot be accepted until the necessary legislation has been passed.

The trial of the tubed-gun may be looked forward to with some interest, as it may prove to afford a sufficient increase of strength to make a safe medium-power gun, principally of cast-iron, and at the same time remedy the fault found in the erosion of a simple cast-iron rifle firing large charges of slow burning powder. Both guns, the hooped and tubed one especially, belong to the transition period from cast or wrought-iron to the built-up steel gun. But because we have delayed the adoption of all-steel guns in this country to so late a period, and take them up not as an experimental but as an established system, we may well avoid the necessity of expending time and money on the further purchase of these composite guns, which ruled for a number of years in France and Italy.

The tubed gun was originally designed to have the steel tube wrapped with wire, and in that design, as does also the present design of the hooped and tubed gun, represents an alternative system of gun construction belonging to a period four years since. This was before we had made any substantial progress in the manufacture of gun-steel forgings in this country, and those designs, offering as they did a satisfactory amount of strength for the anticipated medium power of the guns, were brought forward to meet emergencies and home facilities. They also offered the advantage of giving orders to our steel makers for steel forgings of a size adapted to the early stages of that industry, and enabled them to acquire experience looking towards the manufacture of larger forgings, such as were figured in the built-up all-steel guns presented for manufacture at the same time. Meantime it became necessary to go abroad to purchase the larger forgings (tube and jacket) for the steel guns.

The tubed rifle, as it is now to be made with a simple steel tube, will have the same general dimensions and weight as the 12-inch cast-iron rifle already described. The tube does not extend through to the breech, but is cut off at the rear at the base of the powder-chamber, and the breech-block is held in a steel sleeve screwed into the cast-iron, so that the longitudinal strain will be supported by the cast-iron body alone.

The hooped and tubed rifle is two calibres shorter in the bore than the preceding, and will weigh fifty-three tons. This gun, built up by the successive shrinkage of the cast-iron on tube, and two rows of hoops on the outside of the cast-iron, is, when compared with a simple cast-iron rifle, or even the tubed-rifle, an exceedingly strong construction. The making of the gun itself, in pursuance of a systematic plan adopted by the Ordnance Department for built-up gun construction, was preceded by an experimental construction embodying a complete section of the gun through the reinforce, that is, a compound cylinder forming a counterpart of the gun section. The section of cast-iron cylinder used in this was cut from the body of the gun-casting, and the steel parts were of similar material to the forgings made for the gun. The objects accomplished by this means were a verification of the shrinkages calculated for the gun, and a practical test of the metals on the same scale as the gun itself. This gun will safely support an interior pressure of 38,000 pounds per square inch without exceeding the elastic limit of the metals, and thus

affords at least double the assurance of safety to be derived from a simple cast-iron gun, which, under some 10,000 less pressure, is strained to near the limit of rupture of the metal. And although a shorter gun than the cast-iron rifle, it will, with the same chamber space, afford more power than that gun, and with safety. A large charge of powder may be used with a greater density of loading and higher pressures, and higher velocities, even with the same weight of shot, will be attainable, and will give an increased energy.

The half tube is inserted with a slight longitudinal shrinkage, in addition to the circumferential ; the object of this being to insure a close joint in the bore where the steel tube ends and the bore passes into the cast-iron. The tube is also continued through to the breech, being threaded and screwed into the cast-iron body for a length of twenty-six inches next the breech. This portion forms a reinforce on the tube, and admits of sufficient thickness of wall to cut the thread for the breech-block in the tube itself. The screw connection between the tube and the cast-iron body transmits the longitudinal strain to the body. The steel parts of this gun make up a little more than two-fifths of the total weight of the piece.

WIRE GUNS.

Two of these guns made after designs presented by Dr. Woodbridge are partly constructed. The work was under way at the Watertown Arsenal, but was suspended in June, 1886, through failure of appropriation for its continuance. On one of the guns, a 10-inch, breech-loading, wire-wrapped cast-iron rifle, the wire winding is completed, and the gun has yet to be finished on the outside, bored, rifled, and fitted with breech-mechanism. The steel forgings and wire for the construction of the second gun—a 10-inch breech-loading steel rifle, longitudinal bars, wire-wrapped—have been procured, but no portions of the gun have yet been put together.

The 10-inch wire-wrapped cast-iron rifle will have twenty-eight calibres length of bore, and weigh twenty-nine tons. The cast-iron body weighs seventeen tons, and is wrapped with 0″.15 square wire with slightly rounded corners, applied (for the most part) with a uniform tension at the rate of 41,000 pounds per square inch of section of wire for nearly one-half the length of the gun, beginning near the breech. The muzzle-half of the cast-iron

body is not covered. A steel trunnion band is shrunk on the outside of the wire, and the portion of wire in front of the band is covered by a steel sleeve, also shrunk on, which will transmit the thrust of the trunnion band to another steel hoop shrunk on the cast-iron body and backed up by a key ring screwed on cold. In the section surrounding the powder-chamber the thickness of cast-iron is 9.835 inches, and of wire 5.49 inches. This gun may be expected to stand with safety an interior pressure of 36,000 pounds per square inch, which is computed to be the pressure necessary to produce a tangential stress of 19,200 pounds per square inch on the cast-iron metal at the inner surface of the chamber. An interesting experiment embodying an investigation of the initial tension in the cast-iron, and the effect produced by winding on the wire, the efficacy of the soldering proposed for the wire, and for general information regarding the construction of the gun, was conducted at the Arsenal preparatory to commencing work on the gun. It comprised the construction of a complete section of the gun, and is described in Notes on the Construction of Ordnance No. 38, to which reference has been made in discussing the subject of initial tension in cast-iron guns. An important result of this experiment was the apparent inadequacy of the soldering process, arising from the failure of the solder to thoroughly penetrate the mass. The soldering, although it would afford some assistance in the longitudinal resistance, is intended especially to hold the wires together to prevent slipping in a circumferential direction when the gun is fired. Another object being to prevent the wire from unravelling if a strand were cut on the exterior by a hit from a shot or other accident. A full account of the construction of this gun, as far as progressed, including a discussion of the strains by Lieut. Crozier, is published in the Report of the Chief of Ordnance for 1886, page 359 *et seq*. The wire-winding machine used in this work is also of Dr. Woodbridge's invention. The type of wire-wrapped cast-iron rifles was commended by the Getty Board as a cheap construction, coming within the manufacturing facilities of the country. The design presented is not considered by its advocates as at all presenting the highest type of wire gun.

The 10-inch steel gun, longitudinal bars, wire-wound, is intended to represent such a type. The design presents a gun weighing twenty-two tons, with thirty calibres length of bore.

The wire-winding extends from the breech to the muzzle. The tube is of steel, and extends entirely through the gun, so that the breech-block screws directly into it. One of the most important features of the gun is the means to be provided to give longitudinal strength. This consists of a casing of longitudinal bars or staves made to form a cylinder fitting the tube over about one-half its length from the breech, and is connected indirectly at its front end with the trunnion band, and at its rear end with the breech-block. The steel tube and trunnion hoops for this gun were procured from Whitworth. The bars and the wire for both guns are of home manufacture. The steel bars and billets were procured principally from the Otis Iron and Steel Co., Cleveland, Ohio. The bars were cold rolled at the works of Jones & Laughlins, Pittsburgh, Pa., and the wire drawn at Trenton, N. J., at the works of the Trenton Iron Co.

The Navy Department has in hand a 6-inch steel tube wire-wrapped gun. It is partly completed, but no work has been done upon it for some time past.

The tests of these guns when completed will best enable an opinion to be formed of their merits. The advantage of wire-wrapping on the cast-iron body over steel hooping is not apparent, as the cast-iron body could be sufficiently strengthened, for the limit of its endurance, by the application of steel hoops, which would besides obviate the danger to be apprehended from any accident which might cut and loosen the outer strands of wire. Wire guns, however meritorious may be the designs projected, and even the results of firing tests of a number already constructed in other countries, have as yet scarcely passed the experimental stage. Their object being to enable the use of excessive charges the difficulty of making them a serviceable construction is enhanced. The mechanical difficulties of the construction enter in the attempt to make a compact and serviceable structure in combining the parts designed to resist the two kinds of strain. There are, however, able advocates of wire gun construction ; it appears also that continuous endeavors are being made to perfect the system, and it is not my intention to discredit trials with this or any other system which embodies as much promise of success as does the wire gun construction.

VI.

STEEL CAST-GUNS.

AT the last session of Congress, by Act approved March 3, 1887, the sum of $20,000 was appropriated for expenditure by the Navy Department for the purchase and completion of three steel-cast, 6-inch, high power rifle cannon of domestic manufacture, one to be of Bessemer, one of open hearth, and one of crucible steel. In response to proposals, bids were recently received for two of these castings to be furnished rough turned and bored, from which the finished guns are to be made. The Pittsburgh Steel Casting Company furnished the bid for a Bessemer casting, and the Standard Steel Casting Company that for the open hearth or Martin-Siemens casting. The crucible steel casting was not bid for. The main features of the specifications bids are as follows:

Casting rough bored and turned.	Cost.	Elastic limit.	Tensile limit.	Ultimate Elongation.	Reduction of area.	Weight of finished gun.	Length of finished gun.
	Dollars.	Pounds.	Pounds.	Per cent.	Per cent.	Pounds.	Inches.
Bessemer steel.	3300.	40,000	80,000	7	7	11,000	193.53
Open hearth steel.	5300.	30,000	70,000	10	5	15,0C0	193.53

These guns when finished will be required to fire a projectile weighing 100 pounds with a muzzle-velocity of not less than 2000 f.s., and to stand the statutory test prescribed by the Act of July 26, 1886, which for Navy guns has constituted a test of ten rounds fired as rapidly as possible. The dimensions of the steel-cast guns proposed are suited to reproduce the interior dimensions of the 6-inch Navy forged steel guns, so that in order to produce the effect required, the charge of powder will be from 48 to 52 pounds, and the pressure probably not less than 15 tons.

In weight and exterior dimensions the Bessemer casting will closely approach the Navy gun, whilst the open hearth casting will make a heavier gun by 4000 pounds. The price asked for these rough finished castings will, when the guns are finished and fitted, make the cost of one *exceed*, and of the other not greatly less than the total finished cost of the 6-inch built-up forged steel guns manufactured at the Washington Navy Yard from materials entirely of home production.

The physical qualities of the metal bear a poor comparison with those obtained in forgings; as, for example; taking a piece of somewhat larger calibre, the forgings for tube of the 7-inch steel howitzer furnished the War Department by the Cambria Co. gave: Elastic limit, 47,250 pounds; Tensile limit, 92,750 pounds; Ultimate elongation, 21.1 per cent.; reduction of area, 29.0 per cent.

We are not informed of the methods proposed to be used in the manufacture of these castings and can only await the trial of the guns to form conclusions. They mark the first step in an attempt to establish the manufacture of steel-cast guns in this country, and our great manufacturing facilities, together with the constant advances now being made in the art of steel casting, may enable us to overcome many of the difficulties encountered in like attempts already made in other countries. And as this is the first step in a matter which, if ever successful, will probably require a number of years to extend itself to the successful production of guns of 12-inch calibre and upwards, it is perhaps unreasonable to cavil at the number and comparatively diminutive size of the guns now to be made. The trial of one 6-inch steel-cast gun of a given make may prove something in regard to 6-inch guns, but, in the face of past experience and present widespread distrust of the suitability of unforged (or unpressed) steel guns, can do little to predicate what result will be obtained with larger castings.

Another potent necessity for making the small calibres at present appears to lie in the capacity of the steel works for making such castings, for there is no doubt but that a special plant must yet be provided for making the larger calibres of steel-cast guns. This is one of the items of expense, which, combined with others, will probably make the cost of production of a gun of large calibre quite as expensive if made in this way as if made of forgings and built up. The amount of metal used for the hollow castings

made or attempted for 12-inch cast-iron rifles was about 240,000 pounds or somewhat more than double the weight of the finished piece. The rule of double the weight holds good in heavy steel castings. Taking for example a 12-inch steel gun, the heaviest casting required for a built-up forged steel gun of this calibre is 40 tons, to be cast in the simplest form of a solid ingot. This gives a rough finished forging of 14.5 tons weight, also less than half that of the casting. Applying these rules to the massive casting of a 12-inch steel-cast gun, the weight of casting, if made hollow, would exceed 100 tons, and if made solid would exceed 120 tons at the least estimates allowable. And for this massive casting a special plant, flask, and all the adjuncts must be provided. If we go to 16-inches calibre the comparison is 84 tons, as the heaviest casting for the forged steel gun against not less than 250 tons for the steel-cast gun. Considering the extreme difficulty of making sound steel castings of even a few tons weight at the present time, how long may it be before such castings as these can be manipulated? For guns of such calibre then it may be said the steel-cast system is, from present lights and practices, a question for the future.

The feasibility of making castings for steel-cast guns up to 10-inch calibre (weight of casting about 60 tons) seems within the reach of appliances that might be readily provided, but that such guns or even smaller ones can be made of good sound material possessing the requisite physical qualities to compare in strength, endurance and power with built-up forged steel guns of the same calibre cannot be conceded. To even approach this it would be indispensable that the steel-cast gun should be made with a proper degree of initial tension. The Rodman method of casting has been proposed, but whether intended to accomplish the introduction of initial tension or not has not been made quite clear by its advocates. The slow process of cooling incident to this method would cause the formation of large weak crystals in the casting, and apparently recognizing this, the advocates of the method have proposed to remove all the initial tension strains by an after annealing. This would, moreover, appear to be a wise precaution, inasmuch as this method of casting is so uncertain in cast-iron and would be much more so in steel, with its greater shrinkage and liability to crack from internal strains in the casting. If, then, the Rodman method is not used for the purpose of

introducing initial tension, the hollow casting is certainly a bad form as proved by Whitworth's trials and tribulations with it. The unsoundness found in the centre of a solid cast ingot is in this case only transferred to the middle of the walls of the gun—a result in every way bad, and which no subsequent treatment can correct.

The idea embodied in the making of steel-cast guns, viz., that steel in a relatively weak condition is abundantly strong for the work required of a gun, is a decided step backwards. The work now required of a gun cannot be measured by the days of Rodman and Wade. A steel-cast gun is essentially not a gun of equal strength, and no addition to the massiveness of the structure can make it so, but only add to the inherent difficulties. The greatest gun-making establishment in the world has gone through all these stages and found this to be true, after years of trial with the massive (forged) construction Krupp turned to making built-up guns.

The best method of procuring initial tension in steel-cast guns seems to be that followed by the Otis Iron and Steel Co., who presented a steel cylinder to the War Department for test in 1884. The cylinder was cast solid, bored, and during three successive heatings in a furnace, cooled from the interior. The initial tension thus produced, tried by the obscure method of cutting a full ring, was indicated to be 16,000 pounds per square inch. The tests of specimens of metal taken from different parts of the cylinder, which was 5 feet long, 24 inches outside and 6 inches interior diameter, did not however warrant the making of a steel-cast gun.

It may be stated as a fundamental principle that to make a gun safe to withstand repeated firings without undue enlargement or rupture it should possess sufficient elastic tangential strength in its walls to meet the strain due to the pressure of the powder gases, and it is desirable to have a considerable margin above this. The elastic resistance of a simple cylinder, that is, one of neutral metal, expressed in terms of pressure of the bore, cannot equal the elastic strength of the metal (determined by specimen tests). If we call P. the pressure and θ the elastic limit of the material, the elastic tangential strength of a simple cylinder may be determined by the formula.*

* Formula (17) Notes on the Construction of Ordnance, No. 35.

$$P=\theta\frac{3(R_1^2-R_0^2)}{4R_1^2+2R_0^2}$$

in which R_1 and R_0 stand for the exterior and interior radii. From this—

If $R_1=2R_0$,	thickness of wall $=\frac{1}{2}$	calibre;	$P=0.5\,\theta$
If $R_1=3R_0$,	" " " $=1$	" ;	$P=0.63\,\theta$
If $R_1=4R_0$,	" " " $=1$ 1-2	" ;	$P=0.68\,\theta$
If $R_1=5R_0$,	" " " $=2$	" ;	$P=0.71\,\theta$

A value of θ equal to 35,000 pounds may be considered at least not too low for the metal to be had in a steel-cast gun. This gives the simple gun an elastic resistance of 23,800 pounds if the wall be 1.5 calibres thick, and 24,850 pounds if the wall be 2 calibres thick, and is certainly far from satisfactory in a gun which will be subjected to pressures of 36,000 pounds or more.

This leads to an examination of how much the elastic resistance of the gun may be improved by the introduction of a proper state of initial tension. An investigation of this question is given in appendix B. The physical properties of the metal assumed for the discussion are :

ρ—Force corresponding to safe compression of metal=40,000
θ— " " " extension " =35,000

The example is for an 8-inch gun in which the thickness of wall is taken equal to 1 1-2 calibres for the section in front of the chamber. This is in excess of the present designs of 8-inch built-up guns. Regarding the liability of the gun to fail under either radial compression or tangential extension of the bore, the limit of its resistance becomes in the first case 38,156 pounds per square inch, but if we admit that the bore may be extended tangentially to the elastic limit the resistance would be 49,130 pounds per square inch. This assumes that the correct state of initial tension has been produced—a practical question which rests in the hands of the manufacturer to solve. But taking even the failing limit under radial compression we find that the introduction of a proper initial tension would increase the elastic resistance over that of a simple cylinder some 14,500 pounds. It appears that a thickness of wall equal to 1.5 calibres is well adapted to the problem as it gives nearly the same value for the pressure which would cause the failing limit under radial compression to be reached and that which would produce an equal extension of the metal throughout the thickness of the wall in the state of action. A purpose of the discussion is also

to call attention to what appears to be the best practical method of experimentation in order to obtain a knowledge of the actual state of initial tension introduced by any given process of manufacture that may be adopted. With this knowledge obtained and a careful record kept of the method of treatment it might be hoped to reproduce the same result in successive castings. A fundamental part of the operation would be to cause the tangential compression of the metal at the surface of the bore to be brought approximately at least to the elastic limit of compression of the metal (in this case assumed to be 40,000 pounds per square inch). This is indispensable to getting the best resistance that the gun will offer.

VII.

BUILT-UP FORGED STEEL GUNS. PROGRESS MADE IN THEIR CONSTRUCTION. PNEUMATIC DYNAMITE TORPEDO-GUN. COMMERCIAL VALUE OF GUN-FORGING PLANT.

THIS type of gun, as we make it to-day, is the embodiment of Prof. Treadwell's clear idea of a gun of equal strength, as announced in 1843; of Chambers' mechanical ideas of breech mechanism and of hooping in layers with the hoops of each layer breaking joints, patented in 1849; of Rodman's elegant exposition of the benefit of procuring initial tension in a gun, published in the same year, and finally of Professor Treadwell's extension of this principle to the application of layers of cylinders or hoops in making a built-up gun.* All these men were Americans, and were pioneers in announcing these principles which cover about all the fundamental ones of the built-up gun. These ideas went on their travels and took root in Europe where money *is* spent on guns and defenses, and where slowly, but surely, side by side with forged or pressed steel there was developed at a comparatively recent date the modern type of built-up forged steel gun which now undoubtedly holds an unrivalled place. The French worked up the breech mechanism, and Vavasseur's practical application of Treadwell's first idea has introduced the jacket piece which performs the double function of affording the means to secure the requisite amount of longitudinal strength, and at the same time properly assists the remaining layers in resisting the tangential strains. The responsible officers of the government realized some years since what was taking place, and like sensible folk concluded that it would be best to expend the public funds, upon the best and the only

* I am aware that Blakely's claim to this is in dispute with Prof. Treadwell's. Both patents were taken out in the same year (1855), and Blakely at the same time announced the principle of "varying elasticity," but this latter finds no special application to-day, and there is little doubt but that Prof. Treadwell's claim to originality in this matter is a just one.

good article in the market. The Navy Bureau of Ordnance, backed up by the Naval Committees of Congress with liberal appropriations, has been successful in doing this; the Ordnance Department of the Army has received appropriations sufficient only to make and test some experimental guns. Both have used their utmost legitimate efforts to make the production of built-up forged steel guns entirely a matter of home manufacture, and have studied for themselves the principles of mechanical engineering involved.

What I shall have to say about these principles will give an outline of the studies of this nature which the officers of the Army Ordnance Department have made, and the knowledge which they have acquired by care and practice in the construction of experimental guns, and in efforts to improve the quality of the steel forgings. I will not be understood as disclaiming our great indebtedness to foreigners for the money and inventiveness and skill they have expended in establishing the superiority of the built-up forged steel gun; but we did not import mechanical engineers to teach us how to build these guns, and we in the Army hope very soon to be put in the present condition of the Navy, that is, to have placed at our disposal a *domestic* supply of the material required for making them. We already know that our steel makers are capable to make the very best grades of gun steel, and it has been shown, as in the case of the Navy Bethlehem contract, that the only requisite to placing an order for steel forgings in this country is that Congress shall appropriate a reasonable amount for their purchase.

The amount of oil-tempered and annealed gun steel forgings which the Ordnance Department has procured from home manufacturers, since 1883, somewhat exceeds 200 tons, which has been supplied by the Midvale Steel Company and the Cambria Iron and Steel Works. A list of the principal forgings, showing when and where made, etc., is given in Appendix A. The forgings were procured for the following purposes in built-up gun construction:

1. For experimental purposes incident to the making of guns.
    a. Shrinkage and specimen tests of steel hoops to determine qualities of metal best suited for purposes of gun construction based on method of treatment in manufacture (1883) (1).

(1) Notes on the Construction of Ordnance, No. 25.

b. Construction of a compound cylinder representing a full section through the reinforce (around chamber) of 8-inch breech-loading steel rifle (1885) (2).

c. Construction of same character for 12-inch M. L. rifled Mortar, cast-iron body (3).

d. Construction of same character for 12-inch hooped and tubed breech-loading rifle, cast-iron body (4).

e. Effect of contact with molten cast-iron, and temporary exposure to a high furnace heat, upon the qualities of oil-tempered steel (5).

f. Frictional resistance to longitudinal separation of finished steel cylinders, shrunk one over the other as in gun construction (6).

g. Shrinkage and specimen tests of forged steel trunnion-hoop to determine qualities of metal throughout the forgings (1886) (7).

h. Examinations of the strains produced by oil-treatment, and the effect of after-annealing in removing injurious strains from the forgings (1887) (8).

II. For the manufacture of guns.

51 Complete sets of forgings for 3.2-inch B. L. field guns, steel.

1 Complete sets of forgings for 5-inch B. L. siege rifle, steel.

1 Complete sets of forgings for 7-inch B. L. rifled howitzer, steel.

50 Complete sets of forgings for 8-inch M. L. converted rifles, including tubes, breech-cups and muzzle-collars.

110 Forged (rolled or hammered) steel hoops for 8 and 10-inch breech-loading rifles, steel, and 2 12-inch rifled mortars, and 1 12-inch hooped and tubed B. L. rifle, cast-iron bodies.

In order to complete the experimental guns authorized by the

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(2) Notes on the Construction of Ordnance No. 32.

(3) Report of the Chief of Ordnance, 1885, page 209.

(4) Report of the Chief of Ordnance, 1885, pages 277 and 314.

(5) Report of the Chief of Ordnance, 1885, pages 317 and 321.

(6) Report of the Chief of Ordnance, 1886, page 22, and Tests of Metals, page 18.

(7) Notes on the Construction of Ordnance No. 39.

(8) Notes on the Construction of Ordnance No. 41.

Act of 1883 the Department, being unable to procure in the United States forgings of the size required, has purchased from Sir Joseph Whitworth and Company the following, which have all been delivered, viz.: Five tubes (1 8-inch, 2 10-inch and 2 12-inch short tubes), two jackets (1 8-inch and 1 10-inch) and five trunnion-hoops (1 8-inch, 2 10-inch and 2 12-inch). Since these orders were filled the Midvale Steel Works has demonstrated its capacity to make forged trunnion-hoops as large as 12-inch, having made one of these for the 12-inch B. L. mortar, and has also succeeded in producing a complete set of forgings, tube, jacket and forged trunnion-hoop included, for an 8-inch steel rifle—the qualities of metal being satisfactory throughout.

The progress made in the manufacture of built-up forged steel guns to date is as follows :

26 3.2-inch B. L. field-guns, steel, have been completed ; the forgings for twenty-five additional guns are on hand, and their manufacture has been commenced at the Watervliet Arsenal.

1 5-inch B. L. siege rifle.
1 7-inch B. L. rifled howitzer, } Completed and in preparation for test.
1 8-inch B. L. rifle steel. Tested up to 101 rounds.
1 8-inch
1 10-inch } B. L. rifles, steel. Forgings procured and manufacture commenced at Watervliet Arsenal.

If one is disposed to ask why no more than this has been accomplished they may be respectfully referred to the Appropriations Committees of Congress, who, for two years past, have deemed it wise to make no appropriations for the armament of fortifications, and this has so crippled operations that the Department has been compelled to discharge even the small force of skilled employees at the Proving Ground, and has been able to accomplish almost nothing in the way of completed guns, except for the smallest calibre. Its officers, however, have devoted this time of waiting to a close and careful study of the best methods to be pursued in the manufacture of gun-steel forgings, and of matters pertaining to gun-construction ; and the extensive and thoroughly practical experiments which the Department has conducted in the use of steel in built-up gun construction in the past four years has given its officers a confidence in this method which could not, perhaps, have been acquired more thoroughly in any other way. Added to this there has been an exhaustive test of the steel field-guns, and a perfectly satisfactory test of an 8-inch steel gun up to 101 rounds. There is no scoring of the bore, and since the gun was hooped to the

muzzle there has been no evidence of weakness or defect in firing 77 rounds.

The physical qualities of the steel forgings accepted is indicated by the following table, which gives the standards established from the results of tests of the forgings manufactured, viz.: By the Midvale Steel Company for field, medium calibre, and sea-coast guns, cylindrical hoops of assorted sizes and forged trunnion-hoops; by the Cambria Steel Works, for medium calibre guns and cylindrical hoops of assorted sizes, and by Sir Joseph Whitworth and Company, for tubes and jackets for sea-coast guns. But the figures given for cylindrical hoops and forged trunnion-hoops of American manufacture represent nearly the minimum results obtained from actual tests made.

Designation of piece.	Length of specimen between gauge marks.	Elastic limit.		Modulus of Elasticity.	Ultimate tenacity.	Elongation after rupture.
		Load.	Extension per inch.			
	Inches.	Lbs. per sq. inch.	Thousandths.	Pounds.	Lbs. per sq. inch.	Per cent.
Tube.	2.0	46000	1.533		86000	22.0
	3.0	46000	1.533		86000	20.0
	4.0	46000	1.533		86000	19.0
Jacket.	2.0	50000	1.666		93000	19.0
	3.0	50000	1.666	30,000,000	93000	18.0
	4.0	50000	1.666		93000	17.0
Cylindrical hoops.	2.0	50000	1.666		90000	18.0
	3.0	50000	1.666		90000	15.0
	4.0	50000	1.666		90000	13.0
Trunnion hoops.	2.0	50000	1.666		90000	18.0
	3.0	53000	1.766		95000	15.0
	4.0	53000	1.766		95000	13.0

The 2.0-inch specimens pertain to field calibres, the 3.0-inch to medium calibres, and the 4.0-inch to sea-coast guns. The modulus of elasticity, determined by testile tests, has been found to vary between twenty-eight and thirty-two millions pounds, the former for tubes and the latter for hoops, but the majority of the tests gave more nearly 30,000,000 pounds. The method of manufacture followed in the forgings made in this country has been to forge by hammer, anneal at a high heat (at least as high as that at which pieces are subsequently treated for oil tempering) then oil temper and subsequently anneal at a lower temperature than that used in the oil tempering process. That Whitworth's process may become the established one in this country is highly probable, but the hammered forgings now made are excellent.

The hardness of this steel (somewhat softer in the tube metal) is about 21 as compared with copper at 3.33. And in the whole range of physical properties the metal admirably fulfills the requisites of gun construction, viz.: A combination of *strength, stiffness, extensibility* and *superior hardness* as compared with any other grade of steel or other metal, adapted to the construction of guns, now made, or that promises soon to be made, in suitable commercial quantities. The wide range of elastic extensibility combined with great stiffness (or resistance to displacement), and a high range of reserve ductility, are the most valuable attributes of the metal.

The tangential strength of any properly constructed gun, unless there be a decided difference in the moduli of the metal composing the wall, is, in general, measured by the product of the movement, which is produced in the metal at the surface of the bore, into the modulus of resistance of the metal in the wall surrounding the bore. To make this clear, we will discuss only the tangential extension limit of the metal and neglect the "set" which might occur from excessive radial compression of the wall of tube. It is proper to observe this latter limit in deducing the shrinkages, etc., for the construction of a gun, but from the various resistances which go to assist the tangential resistance of the gun under fire, we may assume that its resistance to an interior pressure is not reached until the metal at the surface of the bore is extended to its elastic limit of tangential or circumferential extension. And further, it will be understood that we are now discussing an all-steel gun, whether built-up or solid, or, any gun of metal of nearly uniform modulus throughout.

With such premises the elastic tangential strength of any properly constructed gun, based upon the well-established fact that the most dangerous displacement of the metal, either in the state of rest or action, takes place at the surface of the bore, is expressed very approximately by the following formula:

$$P = C\,(a + b)\,E^{*} \qquad \text{(D).}$$

In which P represents the pressure per square inch within the bore for the state of action; C is a constant whose value depends only upon the interior and exterior radii of the wall; a and b represent the limits of tangential compression and tangential extension

* See equation (1) Appendix B, from which this equation is derived by placing:

$$C = \frac{3(R_1^2 - R_0^2)}{4R_1^2 + 2R_0^2}, a = \frac{\rho}{E}, b = \frac{\theta}{E}$$

in the metal of the surface of the bore for the state of rest and action respectively, hence the sum (a + b) represents the whole range of dilatation of the bore when the gun is fired; and E represents the modulus of elasticity of the metal composing the tube and supposed nearly constant throughout the wall.

Taking, for example, a gun with thickness of wall equal to $1\frac{1}{2}$ calibres, $R_1 = 4R_0$, and the value of the constant C is 0.682, hence equation (D) becomes,

$$P = 0.682\ (a + b)\ E.$$

Now to apply this to various guns:

1. The built-up forged steel gun is one in which the principle of initial tension is applied with certainty, and the metal, at the surface of the bore, is compressed with exactitude to the limit of tangential compression in the state of rest. Hence the range of dilatation of the bore under the action of the powder gas-pressure, to reach the limit of tangential strength, is expressed by the sum (a + b) or, by 2a if we consider a equal to b, as is generally done for forged steel.

The value of a—the elastic extension or compression per inch—taken from the table giving the physical qualities of the tube metal is 0.001533, and E = 30,000,000. Hence the elastic resistance of the built-up forged-steel gun is:

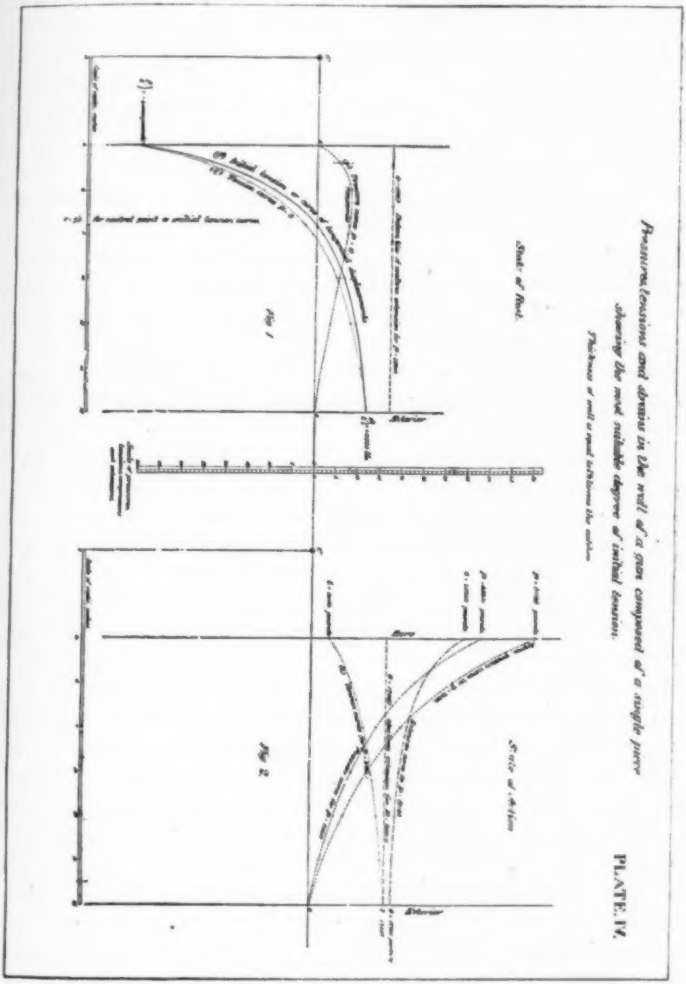
$P = 0.682\ (0.001533) \times 2 \times 30{,}000{,}000 = 62{,}744$ pounds per square inch.

The application of this formula also shows why it is advantageous to the strength of the gun to have outside cylinders with a high modulus of elasticity relatively to the tube—always supposing that the tube combines a high degree of elastic extensibility in connection with its low modulus, for, in that case, the value of E, which in the formula represents the modulus of the tube metal, ought to be raised to about an average of the moduli of the metal in the different cylinders to reach an estimate of the resistance of the gun.

2. In the case of a steel-cast gun *supposed* to have been constructed with a properly regulated initial tension (see Appendix B). If we retain the modulus E = 30,000,000, and take a = 0.00133 and b = 0.001166, the relative values corresponding to p = 40,000 and θ = 35,000 pounds per square inch. The elastic tangential resistance of the gun would be:

$P = 0.682\ (0.00133 + 0.001166)\ 30{,}000{,}000 = 51{,}150$ pounds

per square inch, which is the same result as will be found deduced in Appendix B. (See Plate IV.)



3. If the steel-cast gun be supposed without initial tension, that is a simple, neutral wall of metal, a becomes equal to zero, and b=0.001166 as before, then the elastial tangential resistance will be:

$P = 0.682 \times 0.001166 \times 30,000,000 = 23,870$ pounds per square inch.

In this case there being no compression of the bore to start with the range of dilatation is on the plus side only, and the elastic tangential strength is curtailed accordingly. And in general terms a gun with neutral wall will have only one-half the strength of a built-up wall, or one in which there has otherwise been introduced a proper degree of initial tension.

4. A cast-iron Rodman rifle. For cast-iron $E = 18,000,000$. Although it cannot be admitted that there is any certainty in the amount of initial tension produced in a Rodman cast-iron casting, we may assume a most favorable case by taking $a = 0.001222$ and $b = 0.000722$, the relative values corresponding to $\rho = 22000$ and $\theta = 13,000$ pounds per square inch. Then the elastic tangential resistance of this gun would be:

$P = 0.682\ (0.001222 + 0.000722)\ 18,000,000 = 23,870$ pounds per square inch, or the same as the steel-cast gun without initial tension.

These guns are all taken to be $1\frac{1}{2}$ calibres in thickness of wall, and a summary gives:

Relative tangential resistance of homogeneous guns:

1. Built-up forged steel gun, 62,744 pounds per square inch.
2. Steel-cast gun, with proper initial tension, 51,150 pounds per square inch.
3. Steel-cast gun, without initial tension, 23,870 pounds per square inch.
4. Cast-iron Rodman rifle, 23,870 pounds per square inch.

The 12-inch cast iron rifle recently tested at Sandy Hook has a thickness of wall surrounding the powder chamber equal to $1\frac{1}{2}$ calibres nearly, so that the value of the constant, C, remains equal to 0.682. If now we may be permitted to assume that the initial tension in this gun is represented by the value 15,750 pounds determined from the breech initial tension ring by the very crude and entirely unsatisfactory method of cutting open the ring as a whole. Then $a = \frac{15750}{18.000.000} = 0.000875$, and retaining, as before, $b = 0.000722$, the elastic tangential resistance of this gun is represented by:

$P = 0.682\ (0.000875 + 0.000722)\ 18,000,000 = 20,607$ pounds per square inch.

It may be said, with perfect propriety, that this gun has stood a number of rounds with greater pressure than this. So do other

guns stand pressures in excess of the calculated, but it is not safe to subject them to such pressures, and we may find in this relative comparison of the strength of guns a very good reason why cast-iron guns are not reliable. They are at every round with full charges momentarily subjected to pressures which exceed a useful limit of strain, and approach the limit of rupture of the metal. The iron having so little extensibility finally shows its failing point in a sudden and disastrous rupture. There can be no good reason given why we should base the strength of a cast-iron gun upon the rupture limit of the metal. The advocates of cast-iron guns do this, but it provides no factor of safety.

We cannot apply the preceding rules to the composite guns made with a cast-iron body as the main feature, because of the difference in the moduli of the metals composing the wall—the computation of the strength of these guns requires a more extended application of the formulas. Evidently, however, in the case of the rifled mortars hooped with steel, the value of the resistance P is much increased over what it would be if the piece were simply cast-iron, because of the much higher modulus of elasticity of the metal of the hoops, which are shrunk on to give their full assistance to the cast-iron in resisting the pressure.

Again, if we take the combined cast-iron and steel gun, with a steel tube lining, it is not permissible to assume that the bore of the steel tube can be made to range through the double limit of stretch. For, in the first place, the bore of tube is not compressed to its limit in the state of rest, as in fact the formulas show it to be best to put these tubes in with a play, or at most a very slight shrinkage; and, in the second place, the little extensibility of the cast-iron body in the state of action causes its limit to be reached before the bore of the tube is extended to its limit. Hence in these guns the limit of dilatation of the bore is curtailed on both sides, and their elastic tangential resistance is considerably below that of the built-up steel gun.

We will now revert to an account of actual operations. The scope of the experiments undertaken to develop knowledge in the construction of built-up guns has already been mentioned, and the results may be summarized. When the making of steel guns and steel forgings for composite guns was authorized in this country there was little known upon the subject of gun steel manufacture, and it was difficult to obtain a correct knowl-

edge of the method of treatment pursued elsewhere. Up to this time the few small gun forgings that had been made in this country had been simply annealed. The scope of existing information is contained in a circular issued April 3, 1883, by the Chief of Ordnance to steel makers in the United States, and afterwards published in his annual report for 1883, page 6, *et seq.*

The first experiment then undertaken by the Department with the able co-operation of Mr. R. W. Davenport, Superintendent of the Midvale Steel Company, was to order three experimental steel hoops of the size required for the guns. These hoops were furnished by the Midvale Steel Company as follows:

One rolled hoop, annealed, oil-tempered, and finally annealed.

One rolled hoop, annealed simply.

One hammered hoop, annealed, oil-tempered and finally annealed.

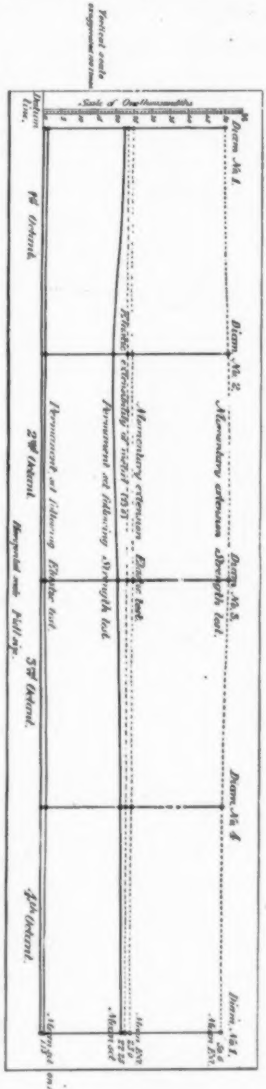
The results of the specimen tests and the shrinkage tests* were: 1st, to establish the superiority of the oil-tempered and annealed metal on account of its high elastic limit and great extensibility within that limit; and 2d, which was not of less importance, to establish a striking similitude between the behavior of the metal in the specimen tests and that of the hoops as a whole in the shrinkage tests. The first of these results was to establish the manufacture of oil-tempered and annealed steel for future constructions; the second, which has been repeatedly verified in experiments since made, gave a basis for all future shrinkage work, since it is upon the tests of detached specimens that we must, in general, judge of the physical properties of the metal.

Plate I, made for the hammered hoop, is given as an illustration of these tests. The figures will explain themselves, but we may note that the very slight permanent set of the hoop, 0.00115 of an inch on a diameter of 15.75 inches following its release from shrinkage in the elastic tests is mainly due to the fact that the hoop in this test was distended beyond the elastic limit of the metal as shown by the specimen tests. The diagram illustrates the great elastic extensibility of steel as a metal and its resilience even when as in the strength test it was distended for hours to nearly double the elastic limit of the metal. The waves of the parts of the circumference of the hoop corresponding to the lines indicate the degree of uniformity of strength in the differ-

* See Notes on the Construction of Ordnance No. 25.

ent several stages of the tests. These lines represent the development of one-half of the interior circumference of the hoop.

The next experiments undertaken were the construction of compound cylinders made to be a complete counterpart of the guns through the reinforce for three different experimental guns under construction, as already mentioned. The purposes of these experimental constructions was fully realized. These purposes were, in general terms: To obtain such data as could be made available in the after construction of the guns; to determine the behavior of the elementary cylinders in combination under the theoretical shrinkages previously deduced by a mathematical application of the formulas and thus test the theories upon which the formulas are based; to observe the individual behavior of the elementary cylinders; and, finally, to determine whether the shrinkages so deduced should be applied in the after construction of the guns or to what extent they should be modified for that construction. I will here refer especially to the results derived from the construction of the section of the 8-inch built-up steel gun.†



Shrinkage tests of Hammered and Oil tempered Hoop, Midvale No. 9883.

Interior diameter of hoop 15.78 inches — Thickness of hoop 2.02 inches.

PLATE I.*

What we may call the "hooping test" in this case, which

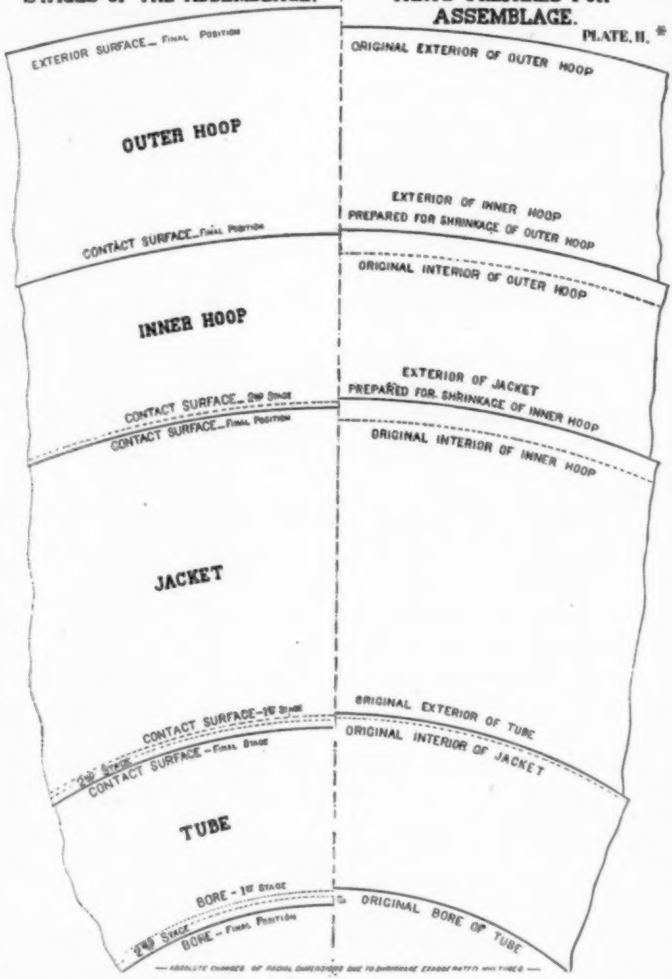
* As here reproduced the scale of the original drawing has been reduced 6⅓ times.

†See Notes on the Construction of Ordnance, No. 32.

comprised the successive shrinkages, one upon another of the 4 cylinders are composing the section of gun (see Plate II.) and the

STAGES OF THE ASSEMBLAGE. | PARTS PREPARED FOR ASSEMBLAGE.

PLATE. II. *



successive dismantling of these cylinders in inverse order, was accompanied by numerous specimen tests of metal cut from the forgings both before and after their subjection to the hooping

* As here reproduced the scale of the original drawing has been reduced 4⅝ times.

test. The several cylinders in the section, viz., tube, jacket, A hoop and B hoop were subjected to the same treatment as required in a gun, that is, they were heated and shrunk in place, and when in place were subjected to the same amount of strain that similar parts would have in the built-up gun in what is called the state of rest, that is, the normal state. The gun section was left in an assembled condition for several weeks. Under these circumstances a comparison of the specimen tests made before and after the hooping tests showed: The elastic properties of the tube metal under compression were decidedly improved, and not materially affected in regard to tensile qualities. The same was observed in regard to the jacket metal which had been subjected to the heat of shrinkage, but the improvement under compression tests was less marked than in the case of the tube. The metal of both hoops showed a loss in tensile qualities varying from 4.85 to 9 per cent., and as a result of these tests it was concluded to give the hoops a margin of 10 per cent. on their elastic strength over any anticipated strains in the gun.

In proving the application of the formulas used in deducing the shrinkages, the radial changes of dimensions for all the cylinders throughout the section were found to be practically the same as those anticipated, in fact the results more than fulfilled the best anticipated, but in respect to changes of length in the cylinders, the formulas did not give accurate results. The formulas applied in this case were Clavarino's*, and it was found that by a modification of these formulas, which consisted in neglecting Clavarino's assumption that the interior and exterior normal pressures acting upon a gun cylinder do also act upon the ends, as though closed—by neglecting this assumption—a set of formulas† was deduced with which the results of the hooping test gave an almost complete agreement. It must not be inferred from this, however, that Clavarino's formulas are considered unreliable. Their use will probably enable the construction of as well proportioned a gun as any other; but failing cases will be found in their application to special features. A very careful consideration reached from this experiment was that the preliminary specimen tests of the metal of the forgings determine suitable values for the physical constants to be used in the computations; and, second, conjointly with this, the formulas applied can be relied

* See Notes on the Construction of Ordnance, Nos. 6 and 7.
† " " " " " No. 35.

upon to indicate with accuracy the results which will be obtained in practice. That is to say, the formulas are proved correct for the various changes and displacements induced by the pressures produced in shrinking the hoops together; hence they may be relied upon to indicate truthfully what will take place in the augmentation of the same pressures in the state of action.

Plate II., which has been carefully constructed to scale, represents the measured changes of radial dimensions, exaggerated 100 times, which took place in each of the cylinders when they were successively shrunk together in this section. The anticipated compression of the 8-inch bore as deduced by the formulas was 0.0129 of an inch, and its measured compression was 0.0131 of an inch; the anticipated extension of the exterior diameter of the outer hoop—31.5 inches—was 0.0285 of an inch, and its actual extension was 0.0276 of an inch, an absolute difference of less than one-thousandth of an inch, and entirely inappreciable when regarded relatively as an extension per inch of hoop diameter or circumference.* The degree of accuracy obtained is seen to be 98 per cent. of the mathematical result anticipated. I will call particular attention to the actual displacements of metal for the different cylinders in order to emphasize the fact that in a built-up gun the shrinkages are (and can be readily made so) so arranged that the residuum of elastic displacement in each cylinder is sufficient to meet the greatest interior pressure that the gun is computed to withstand; and, in addition to this, the actual elastic resistance of the built-up forged steel gun is always made much greater than is necessary to withstand the powder pressure obtained in practice. Then it amounts to this—none of the cylinders will be strained nearly to the elastic limit by the powder pressure. Referring to Plate II., the maximum strains in the several cylinders stand in relation to the elastic properties of the metal as follows:

Bore of tube *compressed*	to	100	per cent.	of	elastic limit.
Interior surface of Jacket	"	20	"	"	"
Interior " A Hoop *extended*	"	63	"	"	"
Interior " B Hoop *extended*	"	65	"	"	"

Now, when the interior pressure—which for this state of the system is *nil*—is introduced, the bore of the tube has double its

* See page 20, Notes on the Construction of Ordnance, No. 32.

range of elastic displacement to go through before the outer limit is reached, the interior of jacket passes from a negative to a very moderate positive extension value, and the two hoops undergo a further extension within the margin of elastic strength left in them—their displacement being relatively small in comparison with that of the bore of the tube because of their remoteness from the action of the central force. A confirmation of these experimental results is shown in the drawing (Plate III.) made to represent the principal features of the construction of an 8-inch rifle.* Lines are drawn to represent the measured compression of the bore of tube due to the shrinkage of the several series or layers of outer cylinders.† The line of final compression is seen to be in close proximity to that representing the anticipated compression, the slight excess of the actual over the anticipated compression being accounted for by the fact that the tube actually used in this gun was a somewhat more yielding one than that for which the shrinkages were computed. If we estimate this excess, however, for the only part of the bore designed to be compressed to the full limit—that is, for the powder chamber—we find the excess of compression to be but one per cent. more than the anticipated. With such results obtained with a gun weighing 13 tons and involving so many shrinkage surfaces, is it not safe for one who has seen this done to claim that the production of the proper degree of tensions in a built-up gun is a *certain* process which, after the plans of the gun are made, requires only competent workmen, good machines and requisite care in inspection to effect its accomplishment. Lieut. Howard's report‡ upon the construction of a number of 3.2-inch field guns at the West Point Foundry (where also the 8-inch rifle was put together) shows by the coincidence between the anticipated and the actual tensions obtained in these guns which contain only one shrinkage surface that the construction is not only practical but its results are sure. A single shrinkage surface makes the anticipated result more difficult of accomplishment, because if there be two or more such surfaces, any error, except what might occur from actual carelessness on the part of the workmen and inspector, due to finishing the work for a preceding surface, can be corrected in the next shrinkage applied.

* The vertical scale of relative compression is actually exaggerated about 100 times only, instead of 1000 times, as written on the drawing.

† See Page 229, Report of the Chief of Ordnance, U. S. Army, 1886.

‡ Appendix Report of the Chief of Ordnance, U. S. Army, 1887.

The experiments* made to determine the effect of a high heat upon oil tempered steel exposed to its action for a short time showed, in one case, that the physical properties of a short section of an 8-inch tube were not materially affected by pouring a quantity of molten iron into a mould surrounding the steel piece and leaving the iron in contact with the outside of the steel for 3.5 minutes. In another case the quality of the metal in a short cylinder of Whitworth gun steel was not injured by the white heat of a furnace applied a sufficient length of time to raise a part of the outer surface of the piece to a dull red heat. In this instance the steel cylinder was shrunk upon a core—one end and the outer surface only being exposed directly to the heat. The utility of these experiments is found in the necessity which sometimes, though rarely, arises to remove a hoop or other cylinder after it has been shrunk in place; indeed the whole gun can be dismantled in this way if necessary. Pouring molten cast-iron around the place to be removed has been found to be the most practical ble method. The pieces thus removed can be used again as it is known that the quality of the metal is not materially affected when the operation is skillfully performed.

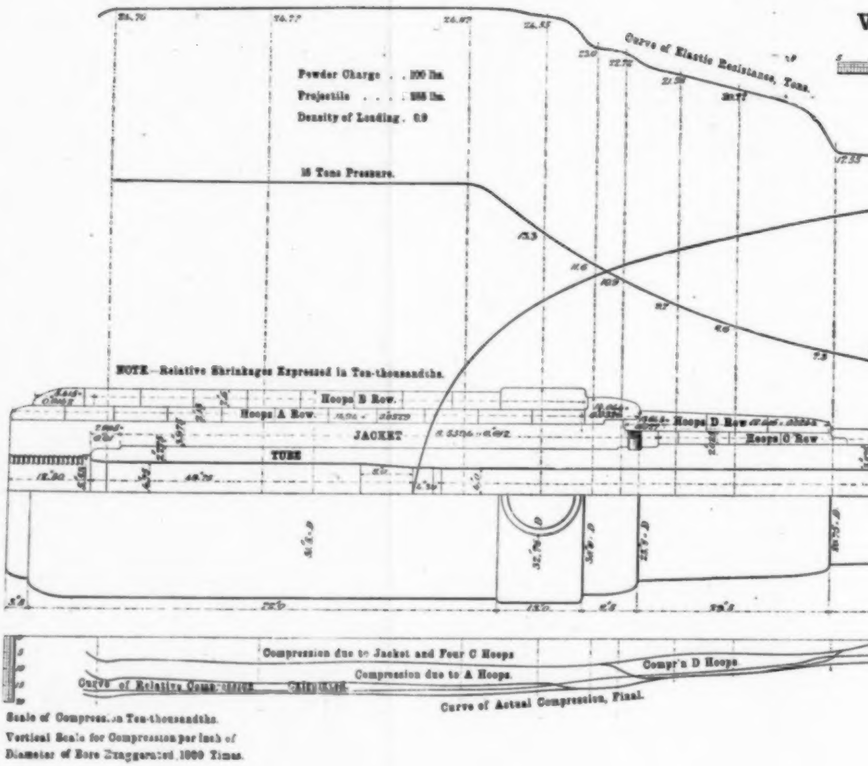
The experiments † to determine the amount of frictional resistance to the sliding of one cylinder over another when shrunk together, in the usual way, were made with special reference to determining what would be the aggregate hold of the jacket shrunk upon the tube in a gun due to this source of resistance alone. That is, to determine what resistance the friction between the two surfaces would offer to any longitudinal displacement of the tube in the jacket. The tests were made with special reference to the plan of pin coupling shown in the drawing (Plate III). The four pins put in near the muzzle end of the jacket would offer an aggregate resistance of about 1,131,300 pounds to shearing, but this being only about one-third of the total effort (3,189,700 pounds) which would be exerted to separate the tube and jacket longitudinally for a pressure of 45,000 pounds per square inch on the breech block, it was necessary to depend upon the frictional resistance for material assistance, and hence it was expedient to test the value of this frictional resistance.

Several hoops, three and four inches in width, were carefully prepared and shrunk upon a piece of gun tube. The pressure

*Report of the Chief of Ordnance, U. S. Army, 1885, pages 317 and 321.

† Tests of Metals, page 18.

8 INC

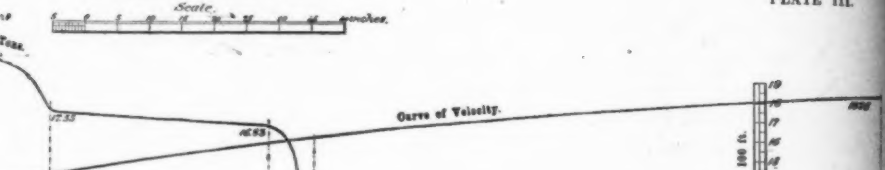


Curve of Elastic Resistance, Tons.
Powder Charge
Projectile
Density of Loading . 0.9
15 Tons Pressure.
NOTE—Relative Shrinkages Expressed in Ten-thousandths.
Hoops B Row.
Hoops A Row.
JACKET
TUBE
Hoops D Row
Hoops C Row
Compression due to Jacket and Four C Hoops
Compression due to A Hoops.
Compr'n D Hoops
Curve of Actual Compression, Final.
Vertical Scale for Compression per Inch of
Diameter of Bore Exaggerated 1000 Times.

INCH B.L. STEEL RIFLE.

WEIGHT 13 TONS.

PLATE III.



NOTE.—This gun is now hooped to the muzzle and weighs 13½ tons.

The following are representative results obtained in experimental firing:

Powder charge........................113 pounds.
Projectile (3½ calibres long).........300 pounds.
Density of loading....................1 (unity.)
Muzzle velocity.......................1852 ft. per sec.
Muzzle energy.........................7132 ft. tons.
Pressure..............................36000 lbs. (16 tons.)

which each exerted upon the tube was determined by the usual formulas and noting the effect of the shrinkage. These hoops were pushed off in the testing machine at Watertown Arsenal. From the force required to start and keep these hoops moving under pressure it was found that the frictional resistance somewhat exceeds 15 per cent. of the normal pressure at the contact surface of two steel cylinders shrunk together as in gun construction. In the gun shown in the drawing (Plate III.) the least pressure at any time (*i. e.*, in the state of rest) existing at the contact surface between the tube and jacket is 7.17 tons per square inch, as computed by Clavarino's formulas. The area of the surface of contact between the two pieces is 3816 square inches, making the aggregate normal pressure about 62,785,000. Taking, for safety, only 10 per cent. of this, instead of 15 per cent., we have over 6,000,000 pounds resistance to sliding due to the friction alone. And as the force tending to slide the pieces is scarcely more than one-half of this, it may be concluded that the resistance to longitudinal separation of the parts of this gun is amply provided for. The pins being in the nature of a security against any start taking place.

In 1885, an 8-inch forged steel trunnion hooped was procured from the Midvale Steel Company. It was the first forged hoop of this character—for sea-coast guns--to be made in this country, and as it was known that the manufacture would present special difficulties, it was determined to make the first an experimental piece, that is, for thorough specimen and shrinkage tests, to determine the quality and uniformity of the metal to be obtained in a forging of that size and character. This forging was treated in the usual way by oil tempering and annealing. The results* of the tests showed an excellent, uniform quality of metal throughout the piece, and incidentally demonstrated a thoroughly good effect of the oil tempering and annealing treatment in a thick and irregular forging.

The gun shown in the drawing (Plate III.) was first tested in the condition there shown, that is, without chase hooping to the muzzle. Since then, however, the piece has been hooped quite to the muzzle. In the first state, after firing twenty-four rounds, the bore of the tube at some fifteen inches from the muzzle was found to have enlarged 0.006 of an inch. The enlargement, although small in reality, was considered sufficiently serious

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* Notes on the Construction of Ordnance No. 39.

to conclude that it would be best to put on the chase hoops, a matter which had been discussed for the original construction. This tube had been received from Whitworth & Co., and it was not certainly known what method of treatment the steel had received, that is, whether it had been carefully annealed after oil tempering. The indications of the firing test pointed to a zone of compressed metal near the exterior surface, probably due to lack of annealing after oil tempering. Such a condition would, as we have already discussed, tend to weaken the tube to support an interior pressure. Then, although the gun steel procured from home manufacturers was known to be in all cases carefully annealed as a final operation in manufacture, experiments were undertaken to analyze the condition of strains left in a piece on the one hand when oil tempered as a final operation, and on the other when annealed after the oil tempering. The method of examination pursued* was that already indicated as proper in examining into the conditions of initial strains existing in a Rodman casting. The results, in brief, were that the pieces of tubes which were annealed as a final operation were almost entirely free from internal strains, whilst the one which was oil tempered, and not annealed, exhibited a state of compression over its entire surface metal, exterior bore and ends, whilst the interior of the mass was in a state of tension.† It may be well here to contradict an impression held by some that the after annealing of the gun steel removes all the beneficial effect of the oil tempering. This opinion would not be held by any one made conversant with the facts in the case, as have been demonstrated by numerous tests made with steel of home manufacture. This question has been pretty thoroughly treated in the discussion before the Naval Institute in January of this year.‡

The first of the new steel field guns—3.2 inch calibre—was

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* See notes on the Construction of Ordnance, No. 41.

† This last condition of affairs was actually found to exist to some extent in the 8-inch gun tube. When the outside of the chase was turned to prepare for hooping to the muzzle the bore of the tube contracted as the metal was turned off, which plainly indicated that there existed a zone of compressed metal at the exterior of the tube. Now becomes apparent the utility of hooping, for a proper degree of shrinkage having been computed for the muzzle hooping, the application of the hoops put this part of the tube into the desired state of initial tension, and all the firing since then has not enlarged the bore at all.

‡ Proceedings of the U. S. Naval Institute—Steel for heavy guns No. 40 (see page 62).

made of steel simply annealed. It has an excellent record for endurance, but at the end of 100 rounds the bore showed an enlargement of 0.009 of an inch at the bottom, thence gradually diminishing to 0.001 of an inch at the muzzle. All subsequent forgings made for these guns have been oil tempered and annealed. In order to test the comparative merits of the two methods of treatment 100 rounds were recently fired from a new gun at Sandy Hook with the result that there was no appreciable enlargement of the bore, except a slight enlargement near the seat of the shot.*

3.2-*inch breech-loading field guns, steel*:—The first of these guns† was made at the Watertown Arsenal in 1884, after designs prepared by the Ordnance Board. The piece consists of a tube covered in one layer by a jacket, trunnion hoop, sleeve and key ring. All these parts are made of forged, oil tempered and annealed steel, and the outer layer, except the key ring, is assembled by shrinkage on the tube. The jacket projects to the rear of the base of the tube, and is threaded within the recess to receive the base-ring which holds within it the slotted screw breech block. The trunnion hoop is connected with the jacket in shrinkage by a lap joint; the sleeve abuts against the trunnion hoop and the key ring, which is screwed on cold—the male thread being cut on the tube—fits close against the muzzle end of the sleeve. The breech-mechanism can be adapted to use either the De Bange gas-check or the Freyre, the latter being a steel ring of triangular section at the side, with a thin front rim or edge, which is forced outward to seal the escape of gas by a conical forcing head on the spindle. Both descriptions of gas check have been fired many rounds at Sandy Hook, and both have given satisfaction.

The piece weighs 800 pounds, and has a length of bore equal to 26 calibres. The first gun made has been fired over 2400 rounds and is still serviceable; and several of the twenty-five guns recently finished have been fired from 100 to 200 rounds, their endurance being entirely satisfactory. The charge of hexagonal powder used with the Freyre gas-check is 3.75, and with the De Bange 3.5 pounds; the weight of projectile is thirteen pounds. For muzzle velocity the 3.75 charge has given 1749 feet and the 3.5 pound charge 1686. A range of 6479 yards, or 3.75 miles, with a mean deflection of 95.6 yards tothe right, is given

* Appendix 39, Report of the Chief of Ordnance, 1887.

† Report of the Chief of Ordnance, 1884, page 509.

with 20° elevation. The mean deviation given at one mile range is about three feet. Taking an average of some 900 rounds the rapidity of fire obtained has been about seventy rounds per hour —the maximum being forty-six rounds in twenty-six minutes, or at the rate of 120 pounds per hour. The type gun of this calibre has been tested and accepted by the board for testing rifled cannon. This board continued the test of the gun up to an endurance of 1800 rounds. The data given above is taken from the results of trials made by the Testing Board.

The 5-inch breech-loading siege rifle and 7-inch breech-loading rifled howitzer were both made at the Watertown Arsenal under the direction of Lieut.-Col F. H. Parker. Both guns are after designs made by the Ordnance Board. In general plan of construction both guns, and more especially the 5-inch siege rifle, are nearly a counterpart on a larger scale of the 3.2-inch field gun. The forgings for the rifle were made by the Midvale Steel Company. The weight of piece is 3500 pounds, and the length of bore 30 calibres. It is fitted with the slotted screw breech mechanism and De Bange gas-check. The details of design of 7-inch howitzer were worked up by the late Lieutenant William Medcalfe. The piece is designed to give 6000 yards range to a shell weighing 105 pounds. The length of bore is 12 calibres nearly, and weight of piece 3750 pounds. The forgings for this piece were made by the Cambria Steel Works, and fully meet the high standard of quality prescribed by the Ordnance Department.

8-inch breech-loading rifle, steel: The manufacture of this gun was completed at the West Point Foundry in June, 1886. The tube, jacket, and trunnion hoop forgings were procured from Sir Joseph Whitworth & Co., and the remaining forgings for hoops and breech mechanism from the Midvale Steel Co. The manufacture of the gun was long delayed by the non-delivery of the forgings from Whitworth, which were not finally received until February, 1885. The general construction of the gun will be sufficiently explained by the drawing (Plate III.) except the breech mechanism which is of the De Bange system.*

The elastic resistance which this gun will offer to interior pressure is 56,000 pounds per square inch; it has, in firing with experimental powders, been several times subjected to pressures

*A full description of the details attending the manufacture of this gun is given in a report made by the writer. (See Report of the Chief of Ordnance, U. S. Army. 1886, page 229.)

of over 40,000 pounds, and two of the records show 44,500 and 46,300 pounds, but the usual pressure will not exceed 36,000 or 37,000 pounds. In any event, for pressures likely to be obtained in service the gun has a large margin of elastic resistance. Up to this time the gun has been fired 101 times with the following charges:

2 rounds with a powder charge of 65 pounds; 12 of 85 pounds; 3 of 95 pounds; and 84 of from 100 to 113 pounds weight. The weights of projectile were: in 7 rounds, 182 pounds; in 4, 235 pounds; in 1, 250 pounds, and in 89, from 285 to 302 pounds. At the 101st round a range of 10,698 yards or a little over six miles was obtained with a charge of 95 pounds of powder and 289 pound projectile. The muzzle velocity for this charge was 1800 f. s., or about 75 f. s. less than would have been obtained with a full charge of suitable powder.

The accuracy of the piece is remarkable. Of five shots following one sighted shot, fired at a target—range 3000 yards—all were placed within a circle of 6 feet diameter.

The following are some of the results obtained in the firing tests of this gun in which a number of different experimental powders have been used:

Round. Numbered.	Powder charge.		Projectile Weight.	Density of loading.	Muzzle Velocity.	Pressure.	Muzzle Energy.
	Kind.	Weight					
		Pounds.	Pounds.		ft. per sec'd.	lbs. per sq. in.	ft. tons.
5	German.	100	182		2144	29500	
6	do.	100	235		1942	32150	
10	Dupont, P.A.	100	235		1938	32950	
24	do. P.K.	100	235		2026	37660	
31	do. P.N.	110	289	0.98	1878	36000	7066
37	German.	110	289	0.98	1875	35900	7043
43	do.	110	302	0.98	1857	37000	7219
58	Dupont, Q.M.	113	300	1.00	1852	37640	7133
64	do. Q.U.	110	300	0.98	1877	40700	7333
73	do. Q.Y.	105	289	0.935	1904		7263
80	do. Q.W.A.	105	289	0.935	1879	36500	7073
97	do. P.N.A.	113	301	1.0	1852	35500	7157

The results obtained with the last samples of powder tried indicate that the muzzle energy of the gun can be placed at 7200 foot tons, obtained with a shot 3 1-2 calibres in length, weighing 300 pounds, and without exceeding a pressure of 37,000 pounds.

WORK DONE BY THE NAVY DEPARTMENT.

The brief outline that can be given of the work of the Navy Bureau of Ordnance will be devoted principally to showing the remarkable progress that has been made by the Navy in the pro-

duction of built-up forged steel guns, and that the question whether this gun shall be the established type of construction in this country is no longer an open one. Not only is the type of gun established, but the home manufacture of the forgings also.

The Midvale Steel Company, which is amply able to fill the orders undertaken, has supplied, or is now under contract to supply, the following complete sets of steel gun forging, as given in Appendix A, viz.:

15 sets for 3-inch B. L. boat howitzer, delivered.

2 sets for 5-inch B. L. rifles, delivered.

52 sets for 6-inch B. L. rifles, of which 20 sets have been delivered.

The recent contract made by the Navy with the Bethlehem Iron Company provides for the delivery of about 1225 tons of steel gun forgings for 6, 8, 10 and 12-inch calibres. Summarizing the whole number of sets of forgings, procured or under contract for delivery, by home manufacturers for the Navy, there are 148 sets, viz.: 15 3-inch, 2 5-inch, 101 6-inch, 4 8-inch, 24 10-inch and 2 12-inch. To get at the whole number of guns made, or now provided for in the Navy, there must be added to the above list 8 8-inch and 3 10-inch rifles for which the forgings were mainly procured from Charles Cammell & Co., and Whitworth, in England. This makes a total of 159 steel rifles, of which 141 are built-up forged steel guns of 6-inch calibre and upwards.

The first built-up forged steel gun, which was also the first of its kind made in this country, was an experimental 6-inch B. L. rifle. A contract was made for this gun by the Navy Bureau of Ordnance with the South Boston Iron Works, January 5, 1880, the company to furnish the steel. The tube, of annealed metal, was obtained from the Nashua Steel Co., but the jacket was supplied by Firth, of oil-tempered steel. The two guns following were also 6-inch, of annealed metal, the forgings for which were procured from the Midvale Steel Co., under orders dated in May and June, 1882. Beginning with 1883, the Midvale Steel Co. have delivered, or contracted for 52 sets of annealed and oil-tempered and annealed forgings for 6-inch guns. The forgings to be delivered under the contract made with the Bethlehem Iron Co. are also to be annealed, oil-tempered and annealed, and it is stipulated that the Company shall begin the delivery of the 6-inch forgings August 1, 1888.

Since the commencement of the active work allowed by appropriations in 1883 and subsequent years, the Navy Bureau of Ordnance has procured the forgings for and has completed or nearly so, 21 6-inch rifles, 8 8-inch rifles, and 2 10-inch. Work on a third 10-inch rifle, to be 34 calibres in length of bore, has been commenced with forgings now at the Washington Navy Yard.

Of these guns the West Point Foundry contracted for the manufacture of 5 6-inch and 2 8-inch rifles. Four of the 6-inch are completed, and the three remaining guns are in the final stage of construction. The South Boston Iron Company contracted for the manufacture of 6 6-inch and 2 8-inch rifles. Five of the 6-inch are completed, and the 2 8-inch are to be completed in March, 1888.

The Washington Navy Yard has completed 2 5-inch, 10 6-inch, 4 8-inch, and 1 10-inch rifles, and has another 10-inch about three-fourths completed. Carriages for all the guns have also been made there, besides a number of 3-inch guns and projectile work.

This much has been accomplished since 1883, notwithstanding the considerable delays made by waiting for the first deliveries of the forgings and the lack of machinery and plant for the new and superior quality of work demanded. At present, the Washington Navy Yard has worked up its plant to a capacity for a yearly product of 25 6-inch, and 10 8-inch guns and carriages, etc., or a proportionate amount of work on other guns. Plans are now in process of development which will make the yearly capacity of the Yard equal to completing 25 6-inch, 4 8-inch, 6 10-inch, and 4 12-inch rifles or a proportionate number of any given calibres.

The finished guns have been subjected to the proof required by law, which constitutes a series of 10-rounds fired with all possible dispatch, and a number besides have been subjected to additional firings at the Proving Ground at Annapolis and in firing practice on ship-board.

All are officially reported to have withstood the firing tests perfectly and to give satisfaction in service. One 6-inch gun has been fired about 300 times, and in the Report of the Secretary of the Navy for 1885, it is stated that 6-inch gun No. 4 had been fired 57 rounds and one 5-inch gun 26 rounds. In the rapid firing tests the 6-inch rifle was fired 10 rounds in 11 minutes, and the

8-inch 10 rounds in 15 minutes, although one of the shots was accidentally dropped in the last trial and occasioned a delay.

In their main features the Navy and the Army steel guns are alike, the most important difference in construction being that, in the Navy guns the trunnion hoops are made of oil tempered and annealed castings and are screwed on cold, while in the Army gun designs these hoops are forged and assembled by shrinkage. in the matter of charges also, the practices differ in that the rule in the Navy is to use a charge of powder equal to about one-half the weight of the shot, whilst in the Army the weight of projectile is made proportionately much heavier. The lighter projectile gives a high velocity with a relatively flat trajectory, which is best adapted, as it is claimed, to the conditions of naval combat. The range given for the experimental 6-inch gun is 3046 yards at 3° 10′ elevation and 7000 yards at 10° 10′ elevation.

The weights of the present type guns which have 30 calibres length of bore and are hooped to the muzzle, are; 6-inch, 10,942 pounds; 8-inch, 28,077 pounds; and 10-inch, 57,485 pounds.

The charge determined for the 6-inch is 53 pounds 4 ozs. of German or 48 pounds, 2 ozs. of Du Pont's brown prismatic powder, and 100 pound projectile, and for the 8-inch 122 pounds of German or 112 pounds of Du Pont's American powder with 250 pound projectile. It is stated that the American brown powder gives the same muzzle velocity as the German with less pressure.

The velocities and pressures realized in the several types of guns reported in 1886-7 (Report of the Secretary of the Navy), are:

Date.	Gun.	Powder charge.		Projectile weight.	Muzzle velocity.	Pressure.
		Kind.	Weight.			
			Pounds.	Pounds.	ft. per sec'd	Tons.
1887	5-inch	American	30.5	60	2011	14.2
1886	6-inch	do.	54.0	100	2105	15.6
do.	8-inch	German	.... .	...	2013	15.5
1887	8-inch	American	113.0	250	2008	15.5

I do not know that it will be necessary to add to the proofs already given of the success of the system of built-up forged steel guns as already achieved in this country. The objections which have been raised to the adoption of the system do not appear to have any force under present circumstances.

There is certainly no mechanical difficulty in making these guns which cannot be overcome by the exercise of proper care in manufacture. The machining of the finished surfaces requires

less care, for instance, than is exercised in making paper rolls in this country, for which a series of rolls several feet in length must be finished so true that when piled one on top of the other no ray of light must pass between them. A variation of 0.003 of an inch is usually allowed in turning the shrinkage surfaces for a gun, which allows any skilled workman, with even a fairly good machine, to accomplish the desired result with ease, a fact which any one can ascertain for himself by consulting the workmen at the West Point Foundry, or any other shop where nicety of workmanship is required. Again, the shrinkages required to procure the maximum resistance of a gun built up of several layers are susceptible of interchange ; that is, a certain aggregate effect is required which may be had by a relatively heavy shrinkage of the first layer and a relatively light shrinkage for the second layer and so on, or the reverse. Measurements taken of the bore after the first layer is applied give an accurate check upon the result, and it is then easy to modify the shrinkage for the application of the next layer if necessary. The question of making a thoroughly good built-up gun of forged and oil-tempered steel is practically a question of skilled workmanship only, and all the allowances which are permitted in the accuracy of finish for the work render it not only entirely practicable but comparatively easy of accomplishment.

The division of the gun into many parts has all the advantage of procuring the very best of material, because of the thorough working which each part receives and the facility for examination of the quality of the material which is afforded. In the construction of the gun these different parts are assembled to give a great economy of material. The jacket affords all the requisite longitudinal strength and also a due share in assisting the tube and hoops for tangential resistance. The hoops are needed for the tangential and not for longitudinal strength, and the methods pursued in their manufacture and application in the gun structure essentially fit them to afford the kind of resistance required of them.

It has also been objected that the heat and strains due to firing would disturb the adjustment of the tensions of the several parts. The best answer to this, of course, is that practice has proved the contrary. Again, Gadaud mentions cases of hoops that were removed from guns after long service—yet resumed practically their original dimensions. When the gun is fired the

heat is by no means confined to the tube, but extends through the gun, so that the distension due to the heat is felt throughout the wall; but the heat due to firing does not affect the strength of the metal, and the distension produced by the heat is not an added strain, so that an equilibrium is established between the force of the interior pressure and the resistance of the gun with strains upon the metal due to this force which scarcely exceed those occurring in the cold state. The tube in a built-up gun is subjected to the greatest strains in the structure, and there is always left a large margin of elastic strength in the outside parts. And supposing the tube to be heated in excess, this effect would simply be equivalent to a case of a gun assembled with a greater shrinkage. Then, in firing, the place of most dangerous strain in the gun—that is at the surface of the bore of the tube—would be under a less instead of a greater strain. The principal objection has been the idea that the introduction of the manufacture would require so long a time as to make it expedient at least to adopt some temporary system of gun construction for immediate use in case of necessity. But this matter has now been neglected so long in regard to the legislation needed for the making of guns for the land service, that at present the manufacturing facilities for making the built-up guns are quite as complete as those for making any other kind of guns; hence, there is no reason on this score why we should not at once proceed to manufacture the best gun.

COMMERCIAL ADVANTAGES OF GUN AND ARMOR FORGING PLANT.

The great necessity for purity and strength of material required in the steel to be produced for war purposes will, as indeed it has already done, give a rapid advancement in knowledge of how best to treat the metal in order to get the best results in steel forgings of every nature required for commercial purposes.

The substantial interests that will accrue to the commerce of the country by the demand for guns and armor of home production are manifold. We have good authority for the statement that the United States is metallurgically independent as to its iron ores, iron and steel, but it is economically at a disadvantage in point of cost of material and labor. This disadvantage works against the growth of large forging or press plants, and also against the production of the best grades of steel required for

many commercial purposes. If the Government will demand guns and armor of home or domestic manufacture, it will enable our own steel makers to produce the heavier forgings required for ship building and other structural purposes to compete with the foreign importations of such material now made, to increase the demand for it in the United States, and to compete with foreigners for the trade of neighboring countries. In other ways, also, the scientific investigations connected with the manufacture of steel and its appliances for war purposes will assist the commercial interests of the country.

The gun plant can be applied to make the best of steel for either the purposes of war or commerce as has been proven in the experience of both the establishments that have up to this time furnished gun forgings to the Government. The manager of one of these steel works states: "Undoubtedly this experience has been of very great advantage to us in teaching what the best molecular condition of the metal is, and we take advantage of the plant erected for the Ordnance work in our regular trade work to give our customers the very best product, and also to change or improve the physical qualities of our commercial products to meet the demands of customers. If a customer wants material in the very best possible condition we use the processes for Ordnance metal. And in meeting the demand for the very high grade metal required for Ordnance our studies have caused constant improvements, and shown us *how* to improve our regular product."

The force of this will be understood in mentioning an instance where the ingots made for a lot of gun hoops in the first order undertaken by a company did not meet the Ordnance requirements, and called forth the statement by officers of the company that it would be necessary for them to learn over again "what constitutes sound steel." And the next lot of ingots produced by pursuing a different method of manufacture fully met the requirements. The method of improving the quality of car axles by treating by the so-called water tempering process at the Cambria Iron Works is very largely due to the care and research made by the capable officers of that company in studying the manufacture of Ordnance metal.* If it be true, as has been recently stated, that there is a present tendency to return to wrought iron

* "Steel Car Axles," by John Coffin. Phila. Amer. Society of Mech. Engrs. November, 1887.

for boiler-plates and axles, the reason can only lie in a careless treatment of the steel manufactured for such purposes, and it will behoove the steel makers and mechanical engineers to learn generally, what many of them do already know, that it is not true even of mild steel that, "it can be badly worked and maltreated with impunity, yet it can be trusted under all circumstances." *

The shrinkage tests of steel hoops (already mentioned) made in connection with gun work, and the formulas applicable to the shrinkages used in guns, already established to be so accurately consistent with good practice, can be profitably studied in connection with the application of hoops or rings for strengthening purposes generally, as used in commerce. In general, if only a single hoop or row be applied it will be sufficient to give a shrinkage somewhat within the elastic stretch of the metal of the hoop to prevent an overstrain. In the case of locomotive and car-wheel tires it appears that the following shrinkages are in use or recommended :

By Krupp : $\frac{1}{100}$ of an inch per foot of interior tire diameter.

Penna. R. R. Co.: $\frac{1}{8}$ of an inch per foot of interior tire diameter.

Midvale Steel Co.: $\frac{1}{10}$ of an inch per foot of interior tire diameter.

These rules give (neglecting the compression of the wheel due to the pressure of the tire) an elongation of 0.833 or 1.04 thousandths per linear inch of interior tire diameter (or circumference). They observe the same care with regard to keeping the tension of the metal within its elastic stretch as is done in making built-up guns. And the tires on locomotive and car wheels are constantly subjected to the worst sort of vibratory action, yet they hold their place for long periods of time. It may be remarked, however, that when as in the Ordnance metal one has a steel possessing (for hoops) from 1.75 to 2.0 thousandths elastic stretch, the shrinkage of a strengthening ring might well be made as great as 1.5 thousandths per linear inch of interior diameter or between $\frac{1}{50}$ and 1 of an inch per foot, and this would presuppose a highly resistant interior body, such, for instance, as the case of a ring shrunk upon a solid shaft. With a hollow interior body where an overcompression from the ring might be feared, it would, of course, be necessary to use a proper thickness of ring. Economy

* Edward Bates Dorsey, C. E. Paper read before the U. S. Naval Institute, January 5, 1887

of metal for the strength required would always be obtained by using the highly elastic and strong Ordnance metal with the greater degree of shrinkage to which it is adapted.

To cite an actual case of a hammer used for forging: The hammer-head of steel is held in place by being shrunk on the end of the bar. It had been assembled with a shrinkage of $\frac{5}{64}$ of an inch on $19\frac{1}{2}$ inches diameter; with this shrinkage the socket of the head broke or cracked under usage. The shrinkage was then reduced to $\frac{3}{64}$ of an inch, but the results were still unsatisfactory, and the head was found to stretch and work loose. The attention of the management then having been drawn to the shrinkage tests of the gun hoops, the results were applied to the case of the hammer-head and a shrinkage of $\frac{3}{128}$ of an inch determined upon. This value gives a stretch not to exceed 1.2 thousandths per linear inch of socket diameter. After this, when the bar broke at one time and was removed, the socket of the head resumed its original diameter. Since the last application with the proper shrinkage ($\frac{3}{128}$) the hammer has been in constant use for about eighteen months and no trouble has been experienced and no movement of the head has taken place.

Mr. Morgan, of the Cambria Works, states that pieces of gun steel rejected in the forgings made for that purpose can be worked down to small sizes for commercial uses, and from the excellence of the stock and its thorough working will bring the highest market prices.* Certainly also there would not be a total waste of any rejected piece of forging, since it could always be handled by the plant at hand, and, as a last resort, heated and cut up under the hammer for remelting. Supposing that steel-cast guns were in vogue, any rejected casting of large size would be a total waste, as there would be, presumably, no hammer plant at hand of sufficient size to handle or break it up. The large castings for steel-cast guns might be cut up in lathes to dimensions sufficient to break up under light hammers, but the cost of this operation would probably preclude its adoption. Finally, on this subject, the establishment of several gun and armor forging plants will place the country in a position to be independent of foreign products for its supply of such war material—a position demanded in time of Peace and absolutely essential in time of War.

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* "Our Coast Defense, its Cost and its Mechanical Problems," by Jos. Morgan, Jr., American Society of Mechanical Engineers, XVth meeting. Washington, 1887.

THE PNEUMATIC DYNAMITE TORPEDO GUN.*

The Pneumatic Dynamite gun which has recently been brought forward, promises to serve an important place as an adjunct to other means of torpedo defense and long-range armor piercing guns in any system of harbor defense that may be adopted. The possibilities of its use in Naval warfare, especially on board of harbor defense vessels, in which, probably, its greatest scope of usefulness will be found, need not be more than mentioned here. But if the present promise of the gun is borne out in extended application to suit the varied conditions of service it will become a necessity for the land defense, and should be used as a gun of position forming part of the shore armament. The trials which have been made with an 8-inch gun of this calibre, at Fort Lafayette, have demonstrated the fact that charges of 55 pounds of explosive gelatine and dynamite can be thrown to a distance of about 1800 yards, with a striking degree of accuracy, the total weight of projectile in this case being 136¼ pounds. The same gun, according to the report of the Naval Board which witnessed trials with the gun, in March, 1887, gave a range of 3868 yards or 2.2 miles with a projectile weighing 139½ pounds.

The great advantage of this gun appears to lie in its ability to throw large charges of high explosives with entire safety, using compressed air as a propulsive force, which may be exploded with destructive effect upon the deck of a hostile ship, or with even greater effect by means of the salt-water fuse used with the projectile beneath the water under or near the ship.

The pneumatic gun cannot be considered a simple contrivance, nor will the establishment of a number of them in our sea-coasts forts, if such a state of affairs is reached, be an inexpensive matter. Its success so far, however, is certainly encouraging, and has warranted the recommendation of the Chief of Ordnance to purchase a gun of the class for trial.

The range of modern heavy guns, from ship-board, is from 7 to 8 miles, and it is an absolute necessity for any properly arranged system of sea-coast or harbor defense that such guns should be met by a number of equally effective guns from shore.

*See Journal of the Military Service Institution, June, 1887, vol. 8, No. 30 p. 169.

VIII.

A REVIEW OF THE PAST THREE YEARS (1888–90). STEEL PRODUCING PLANTS; GUN MANUFACTORIES; ARMY GUNS AND RIFLED MORTARS; 16-INCH B. L. STEEL-RIFLE; NAVAL GUNS; STEEL-CAST GUNS; EXPERIMENTAL GUNS; STEEL WIRE-WOUND GUNS; CAST-IRON MORTARS; PNEUMATIC DYNAMITE GUNS.

THE surroundings of the question of coast defense to-day and as they appeared three years since are in striking and happy contrast. Then we were appealing to an only half-awakened public sentiment and striving to prove that the time was ripe to begin, and now we are in the midst of a busy scene of action. No longer are we called upon to repress the sigh of envy at the happy progress of the Navy in building its ships and guns. The opportunity is now afforded the Army to do its part and prepare the solid works of coast defense which will stand as the bulwarks of our harbors, ever ready to concentrate their fire at effective ranges upon an approaching enemy, which a hostile fleet cannot avoid or out-manœuvre, which fire their guns from a stable platform and which possess immunity from destruction by torpedoes, hidden rocks or collisions. Now, I rather believe, some of our nautical allies are disposed to minimize the importance of the land and shore defenses and to put too much confidence in ships alone as a means of coast defense. I may say that these remarks are called for largely because of the fervor with which the public press is propagating the naval idea at this writing. As an illustration of this we may extract the following from an article in the New York *Times* of December 3, 1890:

"The question of the relative advantages of a mobile and stable defense has long been under debate. Without entering into the various arguments advanced pro and con, it is sufficient that the best military minds of the day are united in favoring a mobile defense. The consensus of opinion on this score is so overwhelming and the reasoning employed by its advocates so conclusive that an unprejudiced mind cannot fail to be convinced."

I would commend to such writers a perusal of the course of lectures upon the "Defense of the Sea-coast of the United States," delivered before the U. S. Naval War College by General Abbot, in 1887, and papers read and discussed before the Royal United Service Institution, London, by Captain Stone, R. A., Rear-Admiral Colomb and Major G. R. Walker, R. E., in 1889, published in the journal of that Institution, Vol. XXXIII., Nos. 147 and 149. The bombardment of Alexandria, of which the best account has been written by Lieutenant-Commander Goodrich,* U. S. Navy, illustrated the comparative inefficiency of naval attack against fortified places. Far from supporting the views of the writer quoted above the "best military minds" agree that no adequate coast-defense can be maintained without fortified harbors. There can in this case be no such successful game of hide and seek as was practiced between parts of the English fleet in the Channel manœuvres. The relative cost of complete harbor defenses including floating batteries, etc., estimated by the Board on Fortifications and other defenses, 1886, and of the fleets proposed by the Naval Policy Board, 1889, is about 3 to 1 in favor of the former for first cost and this ratio would be rapidly increased by the cost of maintenance and repair of ships, in comparison with that of permanent shore defenses.

The lines of development of gun-making in the United States have progressed so nearly in the same directions, as discussed in 1887, that there is little relating to principles of construction to add to the paper then read in order to make it presentable at this time. The three years, however, have been otherwise productive of events of such deep and important interest as to wholly change the aspect of affairs. These events have indeed completely disembarrassed the situation of the perplexities which at that time burdened my subject. In brief we may say that Congress is making liberal appropriations for coast defense, the built-up forged steel gun has been recognized as the proper weapon, cast-iron has been again tried and failed and a like fate has befallen cast-steel in the guns tried by the Navy Department.

The Act of Congress making appropriations for fortifications, etc., under the War Department, which became a law September 22, 1888, gave bright promise that an era of activity in coast defense such as had not occurred since about the close of the Civil

* Report of the British Naval and Military operations in Egypt, 1882.

War was to be inaugurated, and the subsequent acts of 1889 and 1890 have fulfilled that promise. As a result of this legislation, now two years in operation, contracts have already been placed with citizens of the United States, embracing such important items as: the steel forgings for 112 field, siege and sea-coast steel guns; the manufacture of 11 eight-inch steel guns, and of 73 twelve-inch sea-coast mortars; the erection of an Army Gun Factory at Watervliet Arsenal, West Troy, N. Y., and the machinery to equip it. A contract has also been concluded for about 430 steel armor piercing shot of 8 and 10-inch calibre, and others for 1 8-inch and 9 15-inch Pneumatic Dynamite Guns.

The question of what guns the Army shall use is now passed upon by a board entitled the Board of Ordnance and Fortification which was appointed pursuant to the act of September 22, 1888. The law enacted that the membership of this Board should comprise the Major-General Commanding the Army, one Engineer, one Ordnance and one Artillery Officer. Besides General Schofield the members of the Board remain as originally appointed, namely, Col. H. L. Abbot, of the Engineers; Col. H. W. Closson, 4th Artillery, and Lt.-Col. Alfred Mordecai, Ordnance Department.

STEEL PRODUCING PLANTS.

Under the ample encouragement afforded by Government orders the Bethlehem Iron Works and the Midvale Steel Co. are steadily developing their plants for the manufacture of steel for war material. At present the gun forgings made there are delivered to the Government to be made into guns at either the Government gun shops or by contract with private manufacturers, but the time appears not far distant when one or both of these establishments will become manufacturers of finished guns. The new and extensive plant of the Bethlehem Co.* for this work is now partly in operation and is rapidly progressing toward completion. The gun ingots are cast under fluid compression and forged by hydraulic press after the Whitworth methods. The open hearth furnaces will have a capacity for casting ingots of 100 tons. The works also include a large plant for manufacture of armor, including a 125 ton steam hammer. This establishment when completed will it is believed compare favorably with any similar one abroad. The Midvale Steel Company whose re-

* Description of the Works of the Bethlehem Iron Co., by W. H. Jacques, Proceedings of the U. S. Naval Institute, Vol. xv., No. 4, 1889.

sources were heretofore severely taxed to produce the forgings for an 8-inch gun are now engaged in extensions of their plant for casting and forging and for treatment, which will shortly enable them to produce the forgings for guns of 12 or 13-inch calibre. The principal items of Government orders for gun forgings placed with these companies (since 1887) are as follows: The Bethlehem Iron Co., by the War Department, for 76 cannon of various calibres with a gross weight of about 2250 tons of forgings; and by the Navy Department, for 128 cannon with a gross weight of about 2725 tons of forgings; the Midvale Steel Co., by the War Department, for 136 cannon with a gross weight of about 540 tons of forgings; and by the Navy Department, for 54 cannon with a gross weight of about 225 tons of forgings.

The Cambria Company of Johnstown, Pa., which at one time promised to be a large producer of gun forgings and steel for war material has apparently relinquished that effort. The Carpenter Steel Works of Reading, Pa., have a contract with the Navy Department involving the amount of $200,000 for steel armor-piercing projectiles of calibres from 6 to 12 inches inclusive; and the Midvale Steel Co. a contract with the War Department for the amount of $100,000 for steel armor-piercing projectiles of 8 and 10-inch calibre.

GUN MANUFACTORIES.

The new Army Gun Factory at Watervliet Arsenal, West Troy, N. Y., owes its present development to the act of September 22, 1888. It was put in operation in September last or two years from the date of the law authorizing its construction and 21 months from the time ground was first broken for building. At that time the power plant, travelling cranes and machine tools were in place, except the large lathes and rifling machines. The first of these lathes to be delivered by the Pond Machine Tool Co., of Plainfield, N. J., is now due, to be followed by others at the rate of not less than one every three months. The present building comprises the north wing and central section to which a south wing will be added to complete the whole as now designed when the necessary appropriations are made. It is an entirely new brick building having a slate roof supported by steel roof trusses. The height is 75 feet. The length of the north wing is 400 feet and of the central portion, containing power plant and shrinkage pit, 165 feet. The width of the north wing is 128 feet.

The proposed south wing will have a ground plan 400 by 158 feet, or 30 feet more width than the north wing to adapt it to the reception of machinery for the manufacture of guns up to 16-inch calibre. The machinery of the north wing is adapted to the manufacture of guns of 8, 10 or 12-inch calibre, the estimated capacity being 24 guns on a basis of twelve 8-inch, seven 10-inch and five 12-inch guns per annum. The south wing, for which appropriation has been made for a travelling crane and a number of the large lathes required, is designed to furnish an additional output of twenty 12-inch guns per annum or an equivalent of work on other calibres. Gun manufacture was first begun near by the site of the new factory at Watervliet Arsenal in November, 1887. During the summer of that year the Department was enabled to devote the sum of about $20,000 from general appropriations to the alteration of a brick timber shed into a small gun shop and the collection there from other points of enough machinery to partly fill the building and commence work. This shop will now be devoted to the manufacture of field and siege guns for which it is at present equipped. The guns which have been completed in this shop during the past two years, comprise 50 3.2-inch and 1 3.6-inch field guns, 1 3.6-inch field mortar, 1 8-inch and 1 10-inch steel sea-coast guns; the conversion of a 12-inch muzzle-loading steel-hooped mortar into a breech-loader, and rifling and making the breech mechanism for a 10-inch cast-iron wire wrapped gun. The heavy cannon now (November, 1890) in hand comprise a 12-inch steel sea-coast gun, a 12-inch steel sea-coast mortar, both of which are nearly completed, and a 10-inch steel wire wrapped gun. Work on five of the sets of 8-inch forgings now being delivered by the Bethlehem Co. is in progress in this and the new factory building.

The Chief of the Navy Bureau of Ordnance states in regard to the new Naval gun factory in his annual report that during the past year the buildings for the gun factory proper have been completed and the 110 ton overhead travelling crane erected on its supports in the north shop, tested and found to be satisfactory. The machines are in place, except the large gun lathes for the north shop for which a contract has been made with Wm. Sellers & Co., which requires the completion and erection of two of the lathes by January 10, 1892, and all of the lathes by April 10, 1893. The flattering comments upon the efficiency of the Naval Gun Factory made by visitors to the works have been

well deserved, and Commodore Folger very pertinently remarks in his report for 1890:

"With the increase in the quality and the amount of the machinery at the naval gun factory and in the adoption of fixed and advantageous methods of shop administration and of settled principles, a large economy has resulted in the production of all material. This is especially apparent in the manufacture of tools, of projectiles, of guns and carriages.

"The following tables illustrate the material advantages above referred to:"

GUNS.

CALIBRE.	Average cost of manufacture.			Average time of manufacture in 10-hour days.	
	Washington Gun Factory.		By contract with private firms.	Washington Gun Factory.	
	1888.	1890.		1888.	1890.
6-inch	$2,649	$1,298	$3,400	115	60
8-inch	5,163	2,772	8,500	125	120
10-inch	6,334	3,500	.....	240	164

6-INCH CARRIAGES.

	Labor.	Material.	Total Cost.
Average of			
First 10	$4,423.10	$2,133.21	$6,556 31
Second 10	3,027.41	1,283.32	4,310.73
Third 10	2,250.74	1,191.25	3 442.09
Fourth 10	1,968.05	1,344.67	3 312.72
Fifth 10	1,708.00	1,116.00	2,824.00

The manufacture of the present type of steel guns was commenced under appropriations made for the armament of ships at the Washington Navy Yard in 1883. In May, 1887, work was commenced on the enlargements and alterations of, and additions to the buildings, etc., which now constitute the new Naval Gun Factory. The number of steel guns above 3-inch calibre which have been completed at Washington up to October 15, 1890, are: 4 4-inch, 2 5-inch, 51 6-inch, 11 8-inch, and 4 10-inch, of which 4 4-inch, 41 6-inch, 7 8-inch, and 3 10-inch have been finished in the past three years.

The West Point Foundry and the South Boston Iron Works

have continued, using about the extent of their resources for the work, to manufacture guns under contract for the Government. Since 1887, the West Point Foundry, having completed its Navy contract for 5 6-inch and 2 8-inch steel guns then outstanding, has further made 6 6-inch guns for that department, and has recently entered upon a contract to manufacture 11 8-inch steel guns for the War Department from forgings delivered by the Government. This company is also engaged in making several 15-inch Pneumatic guns under the existing contract of the War Department with the Pneumatic Dynamite Gun Co. of New York.

The South Boston Iron Works have also completed 6 6-inch steel guns for the Navy in addition to its contract for 6 6-inch and 2 8-inch guns outstanding in 1887. The War Department has recently made two contracts with this company involving the making of cast-iron bodies for 43 12-inch sea-coast mortars and the completion of the mortars with the steel hoops and breech-mechanism forgings to be delivered by the Department.

The Builders' Iron Foundry, of Providence, is a new producer for the Government, secured by the War Department contracts of 1889, for making the cast-iron bodies for 30 12-inch sea-coast mortars and completing the same with the steel hoops and breech-mechanism forgings delivered by the Department. The plant of this company, like the two preceding, comprises a cast-iron foundry, and finishing shops of limited extent for gun work. In the latter respect it has been much improved since the contracts referred to were made and the machine work now being done on the mortars is highly creditable, as was also the quality of the cast-iron bodies the contract for which has been filled.

The manufacture of rapid fire guns and Hotchkiss revolving cannon is conducted by the Pratt and Whitney Co. and the Colt's Patent Fire Arms Manufacturing Co., both of Hartford, Conn., the former for the Hotchkiss Ordnance Co. and the latter for the Driggs Ordnance Co. Up to January, 1891, the number of Hotchkiss rapid fire guns manufactured in this country was: 42 6-pounders, 34 3-pounders and 12 1-pounders; also 44 37 m.m. revolving cannon. The Colt's company has in hand government orders on the Driggs Co. for a number of 6, 3 and 1-pounder rapid fire guns.

Congress by legislation in the past two years has held out inducements for private manufacturers to enter upon the con-

struction of a large number of the guns desired for coast defense and thus bring about the desired object of establishing in this country one or more private establishments fully equipped for the manufacture of finished guns of large calibre in quantity, for home as well as foreign trade. The failure of these negotiations so far seems to have been largely due to a state of unpreparedness on the part of such establishments as might be expected to make a success of the undertaking. Foreign establishments of this kind, for example, Krupp, the Creusot, Armstrong and Whitworth are generally complete in all the requirements for the manufacture of the material that enters into the gun as well as the finished product—not only so but such establishments are large producers of commercial products besides, and such may be reasonably regarded as the necessary concomitants of a private gun making establishment. It may not be expected, theretore, that a private concern for the simple machining of forgings to be procured from other parties can be successfully conducted on a large scale. Provided the present policy of the Government in regard to coast defense be continued the development of one or more large producing private gun making establishments cannot be long delayed and they will be the more healthy in proportion as they combine an adequate steel-producing and machining plant for other purposes as well as gun making.

ARMY GUNS AND RIFLED MORTARS.

The status of Army guns at present in course of production may be briefly indicated by dividing them into two classes: the first to embrace the steel guns and rifled mortars which are intended for present service, and the second the experimental types ordered for tests to determine their merit. A list of the first class with data relating thereto and a statement of the number of guns, etc., ordered and completed to November, 1890, is given in the following table.

United States Army Breech-Loading Rifled Ordnance 1890.

Calibres.	Weight.	Total length.	Length of bore.	Charge. Powder.	Charge. Projectile.	Powder pressure.	Initial velocity	Muzzle energy.	Number of guns, etc. Ordered.	Number of guns, etc. Completed.
	Pounds.	Feet.	Calibres	Pounds.	Pounds.	Tons	Feet.	Ft-tons.		
MOUNTAIN AND FIELD ARTILLERY.										
3-inch Mountain gun, steel.	218	3.9	14.	0.88	12.	6.5	870.	63.	1	1
3.2-inch Light field gun, steel.	829	7.56	26.	3.75	13.5	15.	1675.	263.	100	75
3.6-inch Field gun, steel.	1181	7.56	23.	4.50	20.	16.	1554.	335.	1*	1
3.6-inch Field mortar, steel.	244	2.75	5.25	1.00	20.	8.	650.	58.	1§	1
SIEGE ARTILLERY.										
5-inch guns, steel.	3660	12.15	27.	12.50	45.	16.	1830.	1000.	11	1
7-inch howitzer, steel.	3710	8.06	12.	9.75	105.	12.5	1085.	857.	11	1
SEA-COAST ARTILLERY.	Tons									
8-inch gun, steel.	14.5	23.21	32.	130.	300.	16.5	1935.	7787.	25	2
10-inch gun, "	30.0	30.60	34.	256.	575.	16.5	1940.	15000.	24	1
12-inch gun, "	52.0	36.66	34.	440.	1000.	16.5	1940.	26000.	16	-
12-inch mortar, cast-iron, steel hooped.	15.25	10.75	9.	80.	630.	12.5	1152.	5796.	74	1
12-inch mortar, steel.	13.0	11.76	10.	100.	800.	16.	1150.	7234.	1	-

* Orders for 24 guns await completion of tests of type gun. § Orders for 16 mortars await completion of tests of type mortar.

The 3-inch B. L. Mountain Gun given in the table is a Hotchkiss gun purchased from the Hotchkiss Ordnance Company. The gun is a built-up steel construction and fires fixed ammunition with metallic cartridge case. The equipment comprises the gun carriage and packing outfit complete, besides a limber to be used for prairie service. Shell and shrapnel are also furnished for trial with the gun. The maximum range of this piece is about 4050 yards.

A complete description of the mechanism and manufacture of the 3.2-inch B. L. field gun is given in appendices 13 and 14, Report of the Chief of Ordnance, U. S. A., 1889. The modifications of the original design have for their principal object to diminish mechanical difficulties of construction and cost. In connection with the principles of construction the most important modification is the substitution of a shoulder ring, for the screw thread in the key ring, to prevent any forward movement of the sleeve. The screw was not effective in holding the key ring up to place under fire. The sleeve is now supported by a shoulder or locking ring and the so-called key ring is bored smooth and shrunk on with a slightly inverted cone to hold it in place. The effect of all the modifications has been to add about 25 pounds to the weight of the gun which is now 829 pounds. The De Bange gas check which has been found to be more easy of adjustment and repair than the Freyre is made for all the more recent constructions. The weight of projectile is increased from 13 to 13.5 pounds to give greater effect to shrapnel, and experiments are in progress to test the accuracy with the band placed 0″ .625 instead of 1″ .25 from the base of projectile with the special object of facilitating the manufacture of shrapnel. This change in the position of band, by decreasing the density of loading, gives an initial velocity of about 1645 feet and a pressure of 14.3 tons per square inch with a charge of 3.75 I. K. H. Powder. Five guns of this model have been fired an aggregate of 4700 rounds in proof and tests at the Proving Ground, including 2500 rounds from the test gun and 1269 rounds from gun No. 18.

The 3.6-inch B. L. field gun, steel, is like the 3.2-inch in general construction but contains fewer parts. The jacket and trunnion piece are combined in one forging which is shrunk upon the tube. The hooping terminates in a short hoop shrunk on in front of the jacket piece and covering the locking ring. The

vent is radial and the breech mechanism essentially the same as that of the 3.2-inch field gun with De Bange mechanism. The type gun* which is now being tested was made at the Army Gun Factory. Various samples of powder have been tested with the object of procuring a suitable brand, which is always a source of more or less difficulty for a new calibre. A sample of Du Pont's sphero-hexagonal powder has given very satisfactory results as follows: charge 4 pds. 6 ozs., projectile 20 pounds, velocity 1560 feet and pressure 35,780 pounds per square inch. As this powder has at the same time given good results in the 3.2-inch field gun and 3.6-inch field mortar it is considered desirable to reproduce it and use it in common for the three pieces.

The 3.6-inch B. L. field mortar is made of a single steel forging, trunnions combined. The breech mechanism is the interrupted screw with Freyre gas check and axial vent. An automatic vent cover keeps the vent closed in every position of the block when the latter is partly or wholly inseited except in the locked position. This piece, which has thus far been fired 212 rounds, uses the same projectile as the 3.6-inch field gun with a maximum charge of 1 pound and reduced charges of 3, 5, 8 and 11 ounces, or five in all, which may, however, be made up of three cartridges containing respectively 3, 5 and 8 ounces, and using two of these in combination to make the heavier charges when required. By varying the angle of elevation between 15 and 45 degrees all ranges from about 300 to 3500 yards may be covered. A preliminary series of firings with I. K. H. powder, which gives an initial velocity of 640 feet with the maximum charge, has given the following results: Angles 15 and 45 degrees: 3 oz. charge, ranges 295 and 566 yards; 5 oz. charge, ranges 559 and 987 yards; 8 oz. charge, ranges 882 and 1689 yards; 11 oz. charge, ranges 1279 and 2162 yards; 16 oz. charge, ranges 1975 and 3391 yards. The times of flight were between 4 and 27 seconds. A charge of 16 oz. of the sphero-hexagonal powder gave an initial velocity of 650 feet with 16,570 pounds pressure.

The low pressure required for the service of this piece makes it unnecessary to use the built-up construction. The simple steel forging treated by hammering, annealing and oil tempering, gives an estimated elastic strength of about 22,000 pounds—the thickness of wall around the chamber being 0.5 of a calibre nearly. The piece is intended for high angle fire chiefly against the per-

* Report of the Chief of Ordnance, U. S. A., 1890, Appendix 23.

sonnel of the enemy, where protected by intrenchments or inequalities of the field from the direct fire of field guns. Its range is nearly three times as great and its projectile 2.25 pounds heavier than that of the Coehorn smooth-bore mortar which it is intended to replace. High angle fire of the accuracy such as can be had from rifled field mortars now receives well-merited attention. The 3.6-inch mortar should it is thought be supplemented by a 6-inch field mortar to be mounted on a field carriage adapted to fire without platform as in the Russian service. The piece would carry a projectile from 65 to 70 pounds weight to a range of 4500 yards and would combine nearly the mobility of the heavy field gun with great destructive power against field works and material as well as the personnel.

Ten each of the 5-inch guns and 7-inch howitzer, siege pieces, are now being manufactured for service, the test guns having been subjected to satisfactory endurance tests of 1000 rounds for the gun and 658 rounds for the howitzer.* Several results of the trials with different powders and charges, and for accuracy, were as follows:

CHARGE.				Muzzle Velocity.	Pressure.	Elevation.	Ranges.	MEAN DEVIATION.		
Powder.			Projectile.					Horizontal.	Vertical.	Absolute.
	Kind.	Lbs.	Lbs.	Feet.	Lbs. sq. inches.	D. M.	Yds.	Feet.	Feet.	Feet.
5" Gun.	Spero-hex.	12.5	45	1825	35575	......	1760	2.08	1.77	2.73
	Black-pris.	15.0	45	1885	34560	......	3000	8.10	4.30	9.50
7-in. Howitzer.	I. K.	9.75	105	1080	27700	4 5	1760	2.82	4.95	5.69
	L. X.	10.00	105	1098	28400	8 5	3000	2.76	5.06	5.76
High angle fire,—reduced charges.								Lateral.	In Range.	
7-in. howitzer.	......	2.0	105	......	......	40	1024	8.4	100.4	
		2.8	94	......	.....	40	2488	9.5	133.4	
		3.8	96	......	......	35	3434	8.1	102.6	
		4.1	105	......	......	35	4311	9.95	93.0	

In firing for rapidity the 5 inch gun required about 18½ minutes for 30 rounds and the 7-inch howitzer about 23 minutes for 20 rounds.

The three calibres of sea-coast steel rifles are of the forged

* Report of the Chief of Ordnance, U. S. A., 1890, Appendices 38 and 39.

steel built-up construction, the principles of which have been discussed in the previous writing. The lengths of bore of the 8 and 10-inch guns have been increased from 30 and 32 to 32 and 34 calibres respectively, the latter to conform to the 12-inch model. The hooping extends to the muzzle and the hoops are made comparatively long and lap-jointed over the chase portion of the gun to couple them together and give additional longitudinal stiffness. The rifling is an increasing twist, commencing at 1 turn in 50 calibres and increasing to 1 turn in 25 calibres at 2 calibres from the muzzle, and continuing uniform thence to the muzzle. The guns are constructed to give each an elastic resistance of about 23.5 tons to an interior pressure, which is about 33 per cent. in excess of the normal powder pressure. The ranges are approximately as follows: at 20° elevation:—8-inch, 6.5 miles; 10-inch, 7.75 miles; 12-inch 8.35 miles, and the maximum ranges, corresponding to an angle of about 42° elevation, would be about 9.25, 10.8 and 11.86 miles respectively.

The firings of the experimental 8-inch gun, completed at the West Point Foundry in 1886, have been continued up to 300 rounds under the direction of the Testing Board * and pronounced satisfactory. The bore is somewhat eroded for a length of about 3 calibres in front of the powder chamber. The accuracy is apparently unimpaired by existing erosion and no apprehension of weakening of the tangential strength is felt, inasmuch as the built-up construction renders the amount of erosion in the tube of very little importance in this respect. A measured range of 6.25 miles for 17° .75 elevation has been observed with this gun.

Drawings and description, by Captain L. L. Bruff, of the manufacture of the 8 and 10-inch rifles completed at the Army Gun Factory during the past year will be found in the Report of the Chief of Ordnance, U. S. A., 1890, appendices 19 and 20. These guns represent in general construction the approved designs for future constructions except that the 10-inch has but 32 calibres length of bore instead of 34. Other points of difference relate chiefly to the changes incident to an increase in the length of hoops for later designs. This 8-inch gun has the merit of being the first all steel built-up gun larger than 6-inch calibre made in this country from forgings entirely of home manufacture. The forgings were made by the Midvale Steel Co. It differs from the

* Report of the Chief of Ordnance, U. S. A., 1890, Appendix 37.

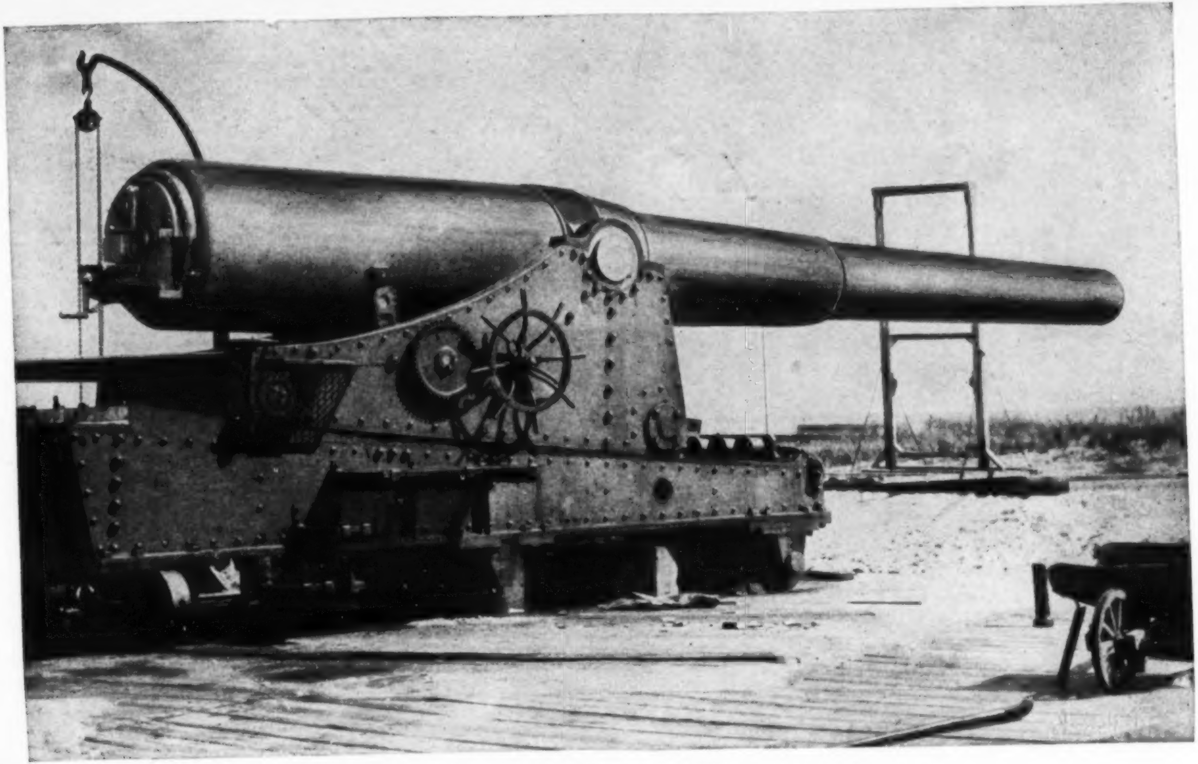
8-inch gun previously mentioned in having but one row of hoops over the reinforce, and the tube is assembled in the jacket by rear insertion. The breech block is seated in a sleeve or bushing screwed into the rear of the jacket and abutting against the rear end of the tube. By this construction the tube is prevented from forward movement by a shoulder bearing within the jacket. The means of longitudinal coupling are much simplified, and smoother outlines obtained for the tube and jacket forgings. The same construction will probably be ultimately used also for the 10 and 12-inch guns which are at present assembled by front-insertion and have the tube and jacket coupled together longitudinally by a locking ring which hooks over the muzzle end of the jacket.

The anticipated results have been fully realized in firing the 8 and 10-inch gun, 76 rounds from the former and 6 from the latter. Full charges gave the following:

Gun.	CHARGE.		Density of loading.	Powder Pressure.	Muzzle Velocity.	Muzzle Energy.	Remarks.
	Powder.	Projectile.					
	Lbs.	Lbs.		Tons.	Feet.	Ft. tons.	
8 in.	130	300	0.9968	16.40	1935	7793	DuPont's Powder.
10-in.	255	571	1.0026	16.64	1953	15113	German Powder

The 12-inch rifle, which is now under construction at the Army Gun Factory, will be sent to the Proving Ground in the spring. The tube and jacket forgings for this gun were procured from Le Creusot, France, and the remaining forgings from the Midvale Steel Works.

The 12-inch B. L. rifled sea-coast mortars, cast-iron, steel hooped, now being made under contract will be rifled with a twist increasing from 1 turn in 40 calibres to 1 turn in 25 calibres at 14.5 inches from muzzle, thence uniform to the muzzle—instead of the uniform twist of 1 turn in 35 calibres used in the experimental piece. The more rapid twist will give accuracy of flight to shell of 5 calibres length probably, but most excellent results have been obtained with the common shell of about 3 calibres length. The piece used for the experiment was the 12-inch muzzle loading steel hooped mortar which was converted into a breech-loader of 12.2-inch calibre, and rifled as above with 68 grooves. The results of three targets of 10 shots each were as follows:



THE 10-INCH B. L. STEEL RIFLE,

MOUNTED ON "PROOF" CARRIAGE.

Mean Range.		Max. Dispersion.		Mean Deviation.		50% Rectangle.		% of hits on ship deck. 330' long by 60' wide.	
		Lat.	In range.	Lat.	In range.	Length.	Width.	Bow on.	Broadside on.
Yards.	Miles.	Yards.	Yards.	Yards.	Yards.	Feet.	Feet.	Per cent.	Per cent.
9683	5.5	8.5	195.4	1.13	44.5	352.2	8.9	67.5	14.2
4532	2.6	19.	66.0	4.04	21.0	166.2	25.4	91.7	29.6
1950	1.1	15.	50.0	4.50	13.9	110.4	35.6	92.2	43.4

The first target was made over water and the two remaining ones over land; at 1950 yards range three of the craters formed in the sand contained two shells each.

The endurance of this type of mortar, cast-iron, steel hooped has now been pretty thoroughly tested. The 12-inch muzzle-loading piece was fired 403 rounds before its conversion to a breech-loader of somewhat larger calibre as cited above, and since the conversion has been fired 68 rounds. And the experimental 12-inch breech-loader has been fired 305 rounds. These tests, accompanied as they have been by accidental bursting of loaded shell in the bore without material injury, ought to remove any reasonable doubt as to the security of these pieces for the services for which they are intended, for it will be noted that they are not called upon to endure pressures exceeding about 28,000 pounds. Higher service, where the locality of the defenses so demands, will be had from the 12-inch steel sea-coast rifled mortar such as the one to be shortly completed at the Army Gun Factory. This mortar is made wholly of steel forgings built-up on a plan similar to the sea-coast guns, and may be subjected to about the same pressure as the guns. The weight of shell to be fired from the steel mortar will be 800 pounds as compared with 630 pounds for the other and its range will be about 6 miles.

16-INCH B. L. RIFLE, STEEL.

On the subject of service calibres for sea-coast defense, it is to be regretted, I think, that the efforts made to produce 16-inch guns have, so far, failed to receive approval by legislation. Designs for 14 and 16-inch steel rifles have been sometime since prepared and the construction of the larger calibre particularly urged by the Ordnance Department. The ballistic elements of the proposed 16-inch gun are: charge 1040 pounds, projectile 2370 pounds, velocity 1950 feet, muzzle energy 62,400 ft.-tons, pene-

tration in iron at muzzle 36 inches and at 5 miles range 24 inches. The objections which have so far hindered the construction of this calibre have been observed to be in order of importance 1st, cost, including the turret mounts, 2d, the lack of need for such heavy calibres and 3d, a doubt as to the practicability of the construction, as witness the case of the 111-ton English guns which drooped at the muzzle and had to be returned to the workshop for repairs.

From a military point of view cost should of course be subservient to necessity, but aside from this the first objection seems shortsighted for the reason that the most important positions must be defended by guns mounted in pairs in armored turrets. The cost of the turrets is the principal item in the expense and would not be much less for 12 than for 16-inch guns. On the other hand a greater number of 12 than 16-inch guns would in general be required to defend a given position so that on the whole the ultimate cost for guns and emplacements would not be materially different whichever calibre be used.

As to the question of necessity, the 16-inch gun is required to give at battle ranges, and occasionally at long range, the penetrative power and destructive effect which is lacking in the 12-inch. Direct hits may not often be counted upon, and except for such hits the 12-inch may be fired with little effect upon the heavily armored ships of the day at two miles range. The striking energy of the 16-inch gun is about 2.4 times that of the 12-inch and its penetration at five miles range as great as that of the 12-inch at one mile. It is a necessity also that the land defense shall possess guns fully equal in power to any that the attack can bring forward. And guns of heavier calibre than 12-inch are not the exception but the rule in navies of the first-class. British sea-going naval vessels carry about 34, the French 54 and the Italian 40 of such guns, none of which are less than 13.4 inches calibre. Still more, we cannot accept a naval estimate of the highest power of gun required, for the land defense should avail itself of its advantages over ship carrying capacity and maintain at all times its natural superiority over naval armament. The ships are limited for space and especially by weight—objections which in themselves are minor matters in shore defenses.

The necessity for the 16-inch guns being admitted the question of making a serviceable gun of that calibre is one of mechanics. For myself I believe that the proposed 16-inch gun, to be built of

steel forgings, which has been so carefully studied and designed by Captain Charles S. Smith, Ordnance Department, in connection with the 8, 10 and 12-inch guns, will, if made with due care, give fully as good a record as the Krupp gun of nearly equal calibre that is serviceable after 200 rounds. The 111 ton English guns were made by contract for home consumption and there were faults of grave importance in the design developed in the trials, which the makers will endeavor to remedy by a partial reconstruction.

NAVAL GUNS.

The table on next page gives a list with average data relating to the guns of the main batteries of our naval vessels, as at present furnished or designed, together with a statement of the number of guns ordered, and those which have been completed.

These guns are all of the built-up forged steel construction; calibres of 6-inch and below comprising a tube and jacket with chase hooping and of 8-inch and higher calibres having the addition of one row of hoops exterior to the jacket. In line with the present tendency in gun construction the newer designs are considerably increased in length and this change has been accompanied by an omission of the muzzle chase hoops, having the tube unhooked for a length of several calibres from the muzzle. The interrupted screw breech closure is applied to guns in service except the 4-inch of which a second type having the Driggs-Schroeder mechanism has been manufactured. A breech mechanism designed by Ensign R. B. Dashiell, to operate for opening or closing the breech by a single movement, is to be tried in the 5-inch rapid fire guns to be manufactured, and if successful will be applied to the 6-inch guns also.

Reference must be made to the annual Report of Commodore Folger, the Chief of the Bureau of Naval Ordnance, to be published with drawings in the Report of the Secretary of the Navy for 1890, for the interesting details it contains in regard to the progress of naval gun construction including the smaller calibres than 4-inch, which form the armament of secondary batteries on ship-board. Propositions are also named in regard to the making of a rifled mortar intended to throw shell containing high explosive, to be mounted on " special vessels as the ram, which are intended to fight at close quarters "; the tests to be made of a submarine gun and projectiles under contract with the Ericsson Coast Defense Co., applicable as armament for the same type of

United States Naval Breech-Loading Rifled Guns 1890.

Calibres.	Weight.	Total length.	Length of bore.	Charge		Powder pressure.	Initial velocity.	Muzzle energy.	Number of guns.	
				Powder.	Projectile.				Ordered	Completed.
	Tons.	Feet.	Calibres.	Pounds.	Pounds.	Tons	Feet.	Ft.-tons.		
4-inch R. F. & B. L. R. Mark I., steel.	1.5	13.7	40.	14.	33.		2000.	915.	35	4
5-inch R. F., steel.	3.1	17.4	40.	30.	50.		2250.	1754.	2	—
5-inch, Mark I., steel.	2.8	13.5	30.	30.	60.		2000.	1664.		2
6-inch, Marks I. II. and III., steel.	4.8 / 4.9	15.8 / 16.3	30.	47. / 50.	100.		2000.	2774.	125	76
6-inch (35 calibres), steel.	5.2	18.8	35.	47.	100.		2080.	3000.	1	1
6-inch (40 calibres), steel.	6.0	21.3	40.	47.	100.		2150.	3204.	2	—
8-inch, Marks I. and II., steel.	12.3 / 13.0	21.5	30.	115.	250.	15.	2000.	6934.	35	15*
8-inch, Mark III., steel.	13.1	25.4	35.	115.	250.		2080.	7498.		
10-inch, Marks I. and II. (30 cal.) steel.	25.1 / 25.7	27.4	30.	240.	500.		2000.	13870.	26	4
10-inch, Marks I. and II. (35 cal.) steel	27.1 / 28.2	30.5 / 31.2	35.	240.	500.		208 0 . / 210 0 .	15000. / 15285.		
12-inch, steel.	45.2	36.8	35.	425.	850.		2100.	25985.	8	—
13-inch, steel.	60.5	40.0	35.	550.	1100.		2100.	32862.	12	—

* Including six guns of Mark III. An 8-inch gun of 40 calibres length has been designed.

vessel; and the contemplated trials of 1-pounder, 3-pounder and 32-pounder Hurst rapid-fire guns. The opinion is advanced that the 13-inch gun will be the largest ever likely to be needed for Naval purposes. The 5-inch rapid-fire gun is intended to be the *standard* quick-firing piece of large calibre and it is of interest to note in this connection that the choice of this calibre has been controlled by the weight of fixed ammunition which can be readily handled. The combined weight of cartridge case, charge and projectile for this gun is limited to 100 pounds. The application of a 6-inch calibre for rapid firing is discountenanced on the ground that the weight of the fixed ammunition would be excessive. Commodore Folger's report also gives the conclusion of the trials by the Navy Department, of the two 6-inch steel-cast guns which were in prominent notice three years since.

STEEL-CAST GUNS.

The two guns tested were made, the one of Bessemer Steel by the Pittsburg Steel Casting Co., and the other of open hearth steel by the Standard Steel Casting Co. It is understood that both guns were cast solid and that the Bessemer casting was bored out and then subjected to a process of heating combined with interior cooling to produce a certain degree of initial tension, but the effect of this treatment has not been ascertained. The open hearth casting is believed to have been simply annealed. The processes of treatment of the castings were left in the hands of the manufacturers and have not been officially published. A number of test specimens—10 from the Bessemer and 12 from the open hearth casting—2-inches length and 0.5 of an inch diameter, were taken from different parts of the castings to represent their physical qualities on delivery. The qualities specified to be obtained and the result of the tests were as follows:

Casting rough bored and turned.	Elastic limit.	Tensile limit.	Ultimate elongation.	Reduction in area.	REMARKS.
	Pounds.	Pounds.	Per cent.	Per cent.	
Bessemer casting: qualities specified.	40000	80000	7	7	
Qualities obtained.	43035 to 55258	73236 to 89278	0.6 to 18.25	1.6 to 21.26	10 spec.
Open hearth casting: qualities specified.	30000	70000	10	5	
Qualities obtained.	30303 to 39861	67735 to 81334	15.45 to 19.55	17.19 to 49.03	12 spec.

The very irregular and unsatisfactory qualities, especially the elongation, shown by the tests of the Bessemer casting might well have deterred the manufacturers from submitting it for the firing test, however, the positive knowledge gained by this latter test that such metal is wholly unreliable is not to be regretted in the interests of science. The tests of the open hearth casting, indicate a fairly reliable metal of its kind, though of insufficient elastic strength for gun construction, even had it been intended for a built-up construction. Both castings showed some imperfections when machined; but those of the open hearth were slight. The rough bored and turned castings were machined and fashioned into 6-inch guns at the Naval Gun Factory, with dimensions of chamber and bore, and breech mechanism modeled after the naval 6-inch B. L. forged steel rifle. The firing tests were made at the Annapolis Proving Ground, the normal charge being the same as for the naval 6-inch gun.

The Bessemer gun was first fired one preliminary round with reduced charge. At the next round the normal charge was used and the gun burst explosively into numerous fragments. The open hearth gun was fired two preliminary rounds with reduced charge, and then subjected to the pre-arranged test of 10 rounds with service charges. As a result the gun was permanently enlarged 0.004 of an inch on the powder chamber and 0.007 of an inch at the compression slope, and defects noted in the bore. The enlargement and defects would have condemned a service piece, and the test was deemed unsatisfactory for the gun. At the request of the company the test of 10 rounds with service charge was repeated in April, 1890. "The result was that the permanent extension of the bore due to the first trial was about doubled near the seat of the projectile, and an enlargement was produced all the way to the muzzle. The flaws reported after the first trial were also observed to be somewhat extended. The gun was therefore finally rejected." The obvious cause of the failure of this gun, aside from the imperfections, was an insufficiency of elastic strength. The powder pressure was not more than 15 tons. The exterior of the gun being 22.2 inches, gave a thickness of 8.1 inches or 1.35 calibres over the bore. The gun having no initial tension, its elastic strength should then be about two thirds of the elastic limit of the metal, from which it appears that this gun might have supported with probable safety a powder pressure not exceeding 10 tons per square inch.

EXPERIMENTAL GUNS.

Notwithstanding the fact that the system of forged steel built-up gun construction has been adopted by the War Department, and guns are being produced on those plans as rapidly as possible, a liberal policy of testing other inventions is pursued. Besides several plans of steel, wire-wound guns, provision has been made for the following:

A 3.2-inch B. L. field gun, steel, fitted with Driggs-Schroeder breech mechanism to be applied to a trial of metallic cartridge cases for field service.

A 3.2-inch B. L. field gun, steel, with Gerdon breech-mechanism, the invention of a mechanic employed at the Army Gun Factory.

A Yates breech mechanism to be applied to a field gun of 3.2-inch calibre.

One Haskell 8-inch high power multicharge gun; and one Mefford 8-inch liquid reservoir gun.

The Driggs-Schroeder and Gerdon field guns are under manufacture by the Ordnance Department. The Gerdon mechanism requires some modifications about the breech of the jacket forging from that used with the service mechanism. The block is pivoted, and revolves to the left in a slot cut through the jacket along the side of the breech recess. There are but two threaded sectors in the breech recess, one at top and one at bottom; opposite the slot the thread is cut away forming a smooth sector. One fourth of a turn is required to unlock the block, and the revolution of the latter to clear the breech begins as soon as it is unlocked. The apparent merits of this mechanism lie in the fewness and simplicity of its parts and rapid working as shown in a model of reduced size. It is at present designed to be fitted with a spindled obturator and plastic gas-check, but if successful in this form will be adapted to fixed ammunition for rapid firing.

The Yates breech mechanism has been tried with an 8-inch gun as mentioned in previous writing. The present trials have not yet been made. The Haskell multicharge gun has been ordered to be furnished outright by the company. It is not known that the construction of this gun has been begun. The principal feature of the Mefford gun relates to a reservoir of liquid interposed between the tube and jacket. This gun has been authorized to be presented for trial and if found satisfacory will be purchased by the Government.

Of another class of guns of recent construction, to-wit: the experimental, composite cast-iron and steel, breech-loading rifles—it only remains to mention here, in continuation of what was said upon the subject in previous writing, that they have been completed and are now in the hands of the Testing Board. The three guns comprised in this class are: one 10-inch wire-wrapped, cast-iron rifle, and two 12-inch B. L. rifles having a cast-iron body, one being lined with a half tube of steel only and the other besides this lining being banded with two rows of steel hoops.

STEEL WIRE-WOUND GUNS.

High-power guns of this description and of service calibre have not yet reached the stage of actual test in the United States, but guns on three different plans are in course of production for trial.

The Woodbridge 10-inch rifle with longitudinal bars, to which reference was made in previous writing, is under construction at the Watertown Arsenal. The gun is being made in accordance with specifications prepared by the inventor who is also employed as an assistant at the arsenal in connection with the manufacture. Varying tensions, decreasing from the interior towards the exterior are employed in winding the wire—the maximum tension to be 116,000 pounds and the minimum 3000 pounds per square inch. The wire is of square cross-section, tinned, 0.15 of an inch on a side. The longitudinal bars were subjected to a preliminary pull in the testing machine amounting to about 80,000 pounds per square inch and certain hoops to an interior fluid pressure of 16,000 to 28,000 pounds per square inch to test the quality of the hoops, and to overcome interior strains which might have been left in the bars from the process of cold rolling to which they had been previously subjected. The hoops, plain and threaded, excepting the key rings, are all to be assembled with shrinkage, and the body of the gun after being wire-wound is to be subjected to a low furnace heat to effect a soldering process through the interposition of sheets of soldering foil laid in the winding between not exceeding five of the outer layers of wire.

About 8000 pounds of the wire needed to complete the amount on hand for this gun was procured from R. H. Wolff & Co. of New York. This wire as well as a lot of 21,000 of 0.1 inch square tinned, made by John A. Roebling & Sons of Tren-

ton, N. J., for the gun to be next mentioned, was promptly produced by the manufacturers. The physical qualities required were readily met, as follows: Ductility sufficient to enable the wire to be wrapped, without rupture, about a cylinder of a diameter equal to the diagonal of its cross-section ; a tensile strength of not less than 160,000 pounds per square inch for all, and for the 0.1 square wire, an elastic limit of not less than 100,000 pounds per square inch. Reports on the manufacture of these two lots of wire will be found in the Report of the Chief of Ordnance, U. S. A., 1890, Appendices 25 and 26. The knowledge that home manufacturers can readily produce a superior quality of the special kind of wire required for guns will greatly facilitate progress in the making of such guns should they be required in quantity.

A 10-inch B. L. steel, wire-wound gun, designed by Captain Crozier, Ordnance Department, is now being made at the Army Gun Factory. It consists principally of a steel tube overlaid from breech to muzzle with a practically continuous covering of steel wire, wound in layers, with a jacket cylinder covering the steel wire over the re-inforce, and a continuous layer of hoops covering the wire over the chase from the trunnion hoop forward to the muzzle. The tube, the end chase hoops, and principal parts of the breech mechanism are steel forgings. The jacket, trunnion hoop and larger chase hoops are intended to be of cast steel, oil-tempered and annealed. A satisfactory casting for the jacket piece seems, however, to be difficult of production, and this may lead to the substitution of a forging for the piece. Cast-steel has been considered suitable on account of cost, and because no higher qualities than those which should be easily attained in a casting can be utilized in the place the jacket occupies in the structure. The wire used in this gun is 0.1 inch square, tinned, and is applied with a uniform tension of about 50,000 pounds per sq. inch in the re-inforce and 30,000 pounds over the chase.

The tube has been subjected to a preliminary winding, over about one half of its length next the breech, with 22 layers of wire wound with a tension of 80,000 pounds per sq. inch, and the wire since removed. The object of this was to overcompress the bore and give the metal a limit of special elasticity of about 60,000 pounds per sq. in. under compression, which approximates the limit of compression to be reached in the ultimate construction. This operation was deemed best in an experimental gun to

secure the desired result; but may be omitted in future constructions by an adjustment of the tensions of wire without preliminary winding. A new feature in manufacture of wire guns is here introduced in electrically welding together the ends of the various coils of wire to give a continuous strand for winding. An electric welding machine for this purpose has been procured from the Thompson Electric Welding Co., and is now in successful operation. It produces an economy of time and labor, and gives a strength of joint superior to that of the splicing and soldering process previously tried. The longitudinal coupling between the tube and jacket is so arranged that it makes very little interruption in the continuity of the wire winding, by which a very desirable quality of construction and equal tangential resistance to interior pressure is attained. The elastic strength of the gun based upon an estimated initial compression of 60,000 pounds per square inch at the surface of the bore, will be 63,000 pounds per square inch. With a powder charge of 267 and projectile 575 pounds the estimated pressure will be 50,000 pounds per square inch, and the muzzle velocity 2231 feet. The finished gun will weigh 30 tons with length of bore 34.15 calibres, and travel of shot 27.55 calibres. The rifling will consist of 60 lands, and grooves with a twist commencing at 1 turn in 50 and increasing to 1 turn in 24.36 calibres within 2 calibres from the muzzle.

Careful experiments in connection with the making of a Brown 5-inch segmental steel-wire wound gun are now being conducted at Reading, Pa., the inventor having the assistance of Lieut. G. N. Whistler, 5th Artillery. An experimental cylinder representing a full section of the gun through the reinforce is now in hand. The principal feature of this construction is the segmental cylinder of varying exterior diameters decreasing towards the muzzle, which forms the inner body, although it may be partly or wholly lined with a thin tube. This part of the structure is made of thin staves to be rolled into shape for fitting together to form a cylinder. It extends the whole length of the gun with the purpose of affording an unusual degree of longitudinal stiffness to the structure. Steel-wire is wound on the outside to produce so great compression at the inner surface of the segmental part, that this surface will not be put out of a state of compression when the gun is fired. It is on this principle that the segmental structure is deemed fit to form the bore surface since there would then be no opening of the joint under fire. The tangential strength of

the gun is afforded by the wire of which the tension and number of layers are arranged to give a sufficient reserve of elastic strength to withstand the powder pressure in addition to the tensions required to give the desired compression of bore. It is stated that entire success has been attained in rolling the staves for the experimental cylinder to such degree of nicety, that no machining of the side faces was required in assembling them into the form of a cylinder.

CAST-IRON MORTARS.

Pursuant to the oft repeated assertions of its advocates that only continued opportunity was needed to prove the reliability of cast-iron ordnance pure and simple, provision was made in the act of Sept. 22, 1888, to test a 12-inch cast-iron rifled mortar in competition with the 12-inch steel-hooped mortar under the direct supervision of the Board of Ordnance and Fortification. The act provided that "should it be shown to the satisfaction of the Board by such tests to be equal in accuracy, range, power, endurance, material and general efficiency to the 12-inch, steel hooped, breech-loading mortar now at Sandy Hook, the mortar and ammunition shall be paid for, including cost of transportation, and contract be made for a further supply of not less than fifty and not more than a hundred * *." The South Boston Iron Works by Mr. Wm. Hunt, who had been the special advocate of cast-iron, undertook to furnish a mortar at their own risk under the act, and the mortar was made under his supervision. The weight, general dimensions and breech, mechanism of the cast-iron mortar were nearly the same as the steel-hooped mortar with some advantage in favor of the cast-iron piece—its maximum diameter being 43.5 inches and weight 14.85 tons, as against 41.75 inches and 14.25 tons for the steel-hooped piece. The programme carried out in the tests of the cast-iron mortar was as nearly as it could be made a duplicate of the firings already made with the steel-hooped mortar—regarding weights of charge, projectile, kind of powder, velocity and pressure. The test was made on the 3d, 4th and 5th of October 1889, in the presence of members of the Board and the representatives of the South Boston Iron Works. At the 20th round the cast-iron mortar burst, explosively, into a number of fragments, which were thrown off with great violence The heaviest charge of powder used was 67 pounds as against the maximum charge of 80 pounds

which has been repeatedly fired from the steel-hooped mortar. A pressure of 29,055 pounds is recorded for the round at which the mortar burst and this was the highest pressure of the series, whilst the steel-hooped mortar has, in the course of several hundred rounds fired from it, withstood pressures of 34,000 pounds without injury. If any further evidence had been needed of the unreliability of rifled pieces of cast-iron pure and simple this test has certainly afforded it.

PNEUMATIC DYNAMITE GUNS.

Ten of these torpedo guns, comprising one of 8-inch and 9 of 15-inch bore are now under contract to be supplied for the land defenses of New York, Boston and San Francisco. The guns are to be furnished by the Pneumatic Dynamite Gun Co. of New York complete with carriages, power plant and all appurtenances for operating them, and will be mounted in groups of 2 or 3 guns forming a battery. The contract specifications which are printed in full in the Report of the Chief of Ordnance, U. S. A., for 1889, impose general conditions for the construction and the performance of the guns which are to be met in the finished product. The materials and construction are inspected by the Government in the course of manufacture, and a report of progress with drawings by Lt.-Col. Farley, Ordnance Department, inspector of the work, will be found in the report of the Chief of Ordnance, 1890. The first contract for these guns is dated March 6, 1889. The time set for their delivery is much overdue, none having yet been completed for trial. In the meantime the company has made one 15-inch gun for the Victorian government which, after a preliminary test at the West Point Foundry, has been sent to Shoeburyness, England, where it will be extensively tested. The explosive to be used in these tests will, it is said, be gun cotton.

The dynamite cruiser *Vesuvius* mounts three 15-inch guns placed abreast and pointing forward at a fixed angle of 18° elevation; the guns are directed by steering the vessel and the range of projectile varied by changing the setting of the valve, which changes the "cut-off," the pressure remaining the same. The statute requirement for the guns of the *Vesuvius*, to-wit, that they shall be capable of throwing shell containing 200 pounds of dynamite or other high explosive at least one mile, was fulfilled in trials made on March 13, 1890, before a board of naval officers. The shells were sub-calibre, 10.5 inches diameter. One shell was

fired from each gun. The total weights were respectively 504.5, 510.5, and 504.5 pounds and the charges 204, 204.5, and 204 pounds of gun cotton, in cluding 50.5 ounces of dry cotton primers in each, the remainder being wet cotton with 35 per cent. average moisture. The ranges attained were 2116, 2233 and 2333 yards. In the tests for rapidity and endurance made before the board October 9, 1889, dummy shell, fitted with gas checks, were used. They were made of iron, full calibre, 7 ft. 1.5 inches long, of rough exterior and without rotating vanes. The firing was begun with the guns empty and breech closed. Sixteen minutes eight seconds were occupied in firing fifteen rounds, five from each of the three guns consecutively.

A connected history of other trials of this system, and reference to official reports will be found in the annual of the Bureau of Naval Intelligence for the years 1887, 1888, 1889 and 1890—particular reference being made to those of the 8-inch and 15-inch guns for some time mounted at Fort La Fayette, New York Harbor—the trials of June 26, 1886, the destruction of the Silliman, September 20, 1887, and the trials in January, 1889. At the last named four full calibre 15-inch shells were fired, of which two were charged with 500 pounds of explosive (dynamite and explosive gelatine). The flight of three of these projectiles was irregular and short, that of the remaining one was steady and attained a range of 1744 yards. Many rounds with 8-inch full calibre and 15-inch sub-calibre projectiles containing charges of the same high explosives have, under Captain Zalinski's fearless and able direction, been fired during the experiments without accident and in general with a good degree of accuracy.

As regards the future of gun construction there is at present a decided tendency to increase the length, which may be noted as the revival of a very ancient practice. It will now be carried, I presume, to the verge of the longitudinal stiffness requisite in the gun and may again retroact. This tendency to increase of length accompanies the development of slow burning powders but may be regarded as preparing the way for the replacement of these powders by their prospective successors the so-called smokeless powders. The perfect combustion of the smokeless powders and their reported behavior even in this early stage of their development indicates that their general adoption for heavy gun charges

will not be long delayed. Such a change will not, however, so far as can be foreseen, cause any material change in the present system of gun construction. The strength of a gun and the work to be done by the gun are correlative, and the standard measure of this work is ever tending to increase, so that the strongest and best gun that can be made will always be demanded.

APPENDICES.

APPENDIX A.

List of the principal steel forgings already procured or under contract for delivery in the United States for the Army and Navy from the Midvale Steel Company and Cambria Iron Works.

Service.	Name of Manufactory.	Date of Order.	Number and Character of Forgings.	Approximate aggregate weight, tons.	Treatment.	Remarks.
Army,	Midvale Steel Co.,	Sept. 20th, 1883,	Fifteen (15) rolled hoops for 12" C. I. hooped, M. L. Mortar.	5	Oil tempered and annealed.	Deliver'd
Navy,	Midvale Steel Co.,	Oct. 6th, 1883,	Eight (8) sets of forgings for 6" B. L. R.	50	Oil tempered and annealed; T hoops, oil tempered and annealed castings.	do.
Navy,	Midvale Steel Co.,	Oct. 6th, 1883,	Two (2) sets of forgings for 5" B. L. R.	12	Oil tempered and annealed; T hoops, oil tempered and annealed castings.	do.
Army,	Midvale Steel Co.,	Nov. 1st, 1883,	Twenty-three(23)rolled and thirteen (13 hammered hoops for 8" B. L. R.	8	Oil tempered and annealed.	do.
Army,	Midvale Steel Co.,	May 21st, 1884,	Twenty-seven (27) rolled hoops for 12" C. I. hooped and tubed B. L. R.	16	Oil tempered and annealed.	do.
Navy,	Midvale Steel Co.,	June 2[illegible]th, 1884,	Twelve (12) sets of forgings for 6" B. L. R.	67	Oil tempered and annealed; T hoops, oil tempered and annealed castings.	do.
Army,	Midvale Steel Co.,	Nov. 21st, 1884.	Fifty (50) tubes, breech cups and muzzle collars for converting 10' S. B. Rodman guns in 8" M. L. R.	80	Oil tempered and annealed. Muzzle collars not treated.	do.
Army,	Midvale Steel Co.,	April 20th, 1885,	Twenty-five (25) sets of forgings for 3".2 B. L. R.	17	Oil tempered and annealed.	do.
Army,	Midvale Steel Co.,	April 20th, 1885,	Tube Jacket and T Hoop forgings for 8" B. L. Rifle.	9	Oil tempered and annealed.	do.
Army,	Midvale Steel Co.,	Sept. 11th, 1885,	One (1) set of forgings for 5" B. L. Rifle, (Siege).	4	Oil tempered and annealed.	do.
Army.	Cambria Iron Works.	Sept. 15th, 1885,	Twenty (20) forged hoops for 10 B. L. Rifle.	15	Oil tempered and annealed.	do.
Navy,	Midvale Steel Co.,	Dec. 31st, 1885,	Forty (40) hoops for 8" and 10" B. L. Rifles.	16	Oil tempered and annealed.	do.

Service.	Name of Manufactory.	Date of Order.	Number and character of forgings.	Approximate aggregate weight, tons.	Treatment.	Remarks.
Army,	Midvale Steel Co.,	June 11th, 1886,	Twelve (12) rolled hoops and one (1) forged trunnion hoop for 12" C. I. hooped B. L. M.	6	Oil tempered and annealed.	do.
Army,	Cambria Iron Works	June 22d, 1886,	One (1) set of forgings for 7" B. L. Howitzer.	2	Oil tempered and annealed.	do.
Army,	Midvale Steel Co.,	Sept. 16th, 1886,	Eighteen (18) forged hoops for 8" B. L. Rifle.	8	Oil tempered and annealed.	do.
Army,	Midvale Steel Co.,	Feb. 19th, 1887,	Twenty-five (25) sets of forgings for 3" 2 B. L.	15	Oil tempered and annealed.	Delivery nearly completed.
Navy,	Midvale Steel Co.,	July 28th, 1887,	Ten (10) sets of forgings for 6" B. L. Rifle.	55	Oil tempered and annealed; T hoops, oil tempered and annealed castings.	Under contract for delivery.
Navy,	Midvale Steel Co.,	Nov. 16th, 1887,	Twenty-two (22) sets of forgings for 6" B. L. Rifle.	120	Oil tempered and annealed; T hoops, oil tempered and annealed castings.	do. do.
Army and Navy,	Midvale Steel Co.,	Various,	For'gs, Miscellaneous hoops, breech mechanism parts, projectiles, shafts castings for projectiles, gun carriage fittings and trunnion hoops.	70	Forgings oil tempered and annealed; castings oil tempered and annealed, and simply annealed.	Delivered.

Total approximate weight, 575 tons.

Aggregate for Army, furnished by { Midvale Steel Company, 168 tons. / Cambria Iron Works, 17 tons. } Total, 185 tons.

Aggregate for Navy, furnished by Midvale Steel Company, 320 tons.

} Excluding 70 tons of Miscellaneous Pieces.

APPENDIX B.

INITIAL TENSION IN GUN CONSTRUCTION.

DISCUSSED WITH REFERENCE ESPECIALLY TO ITS APPLICATION IN STEEL CAST-GUNS.

THE object here will be to show what state of initial tension should be introducing in a hollow steel casting to put it in condition to resist the greatest interior pressure compatible with the dimensions of the cylinder and the quality of its metal. It is immaterial to this discussion whether the tension be introduced in cooling as with a hollow casting, or whether the casting be made solid, then bored and put in the proper state of tension by subsequent operations—provided only the metal is sound and good throughout.

To make the resistance to interior pressure a maximum, the state of initial tension should be such that when the pressure acts from within, the thickness of metal through the wall of the piece should be, as nearly as practicable, uniformly strained to the elastic limit of the metal.* The aggregate resistance of all the cylindrical laminæ would then evidently be a maximum, and it is this aggregate resistance which holds the interior pressure in equilibrium. In the initial state of a gun or cylinder constructed to fulfill this object, the interior portion of the wall rests in a state of tangential compression which is greatest at the surface of the bore, and the exterior portion in a state of tangential extension which is greatest at the outside surface. The strains of compression and extension are in equilibrum—the aggregates of the two being equal quantities. There will be a neutral lamina in the wall where the tangential strain is virtually zero, and from this locality the compressions should increase progressively toward the bore and the extensions likewise, toward the outer surface. If the initial tension be properly regulated, the maximum place of strain will be at the surface of the bore, hence, if the tangential compression there be limited to the elastic limit of the metal under compression, the strain will nowhere exceed the elastic limit of the metal.

To illustrate the problem, take the case of a gun of 8 inches calibre, having a thickness of wall in front of the powder chamber equal to $1\frac{1}{2}$ times the calibre of the gun.

Let

P = Interior pressure per square inch.
ρ = Force corresponding to compression of metal.
θ = Force corresponding to extension of metal.
$\left.\begin{matrix} p \\ t \end{matrix}\right\}$ The radial pressure and tangential tension for the state of action, at any point at the circumference of a circle of radius r.
$\left.\begin{matrix} p' \\ t' \end{matrix}\right\}$ = Similar quantities for the state of rest.
R_0 = Radius of bore, and R_1 = exterior radius of cylinder.
E = Modulus of elasticity of metal.
ρ and θ may not exceed the limit of elasticity of the metal under free tests.

* It will be shown hereafter that for a given quality of metal a condition of uniform strain throughout the wall *equal* to the elastic limit of the metal can be attained for a certain thickness of wall only, that is for a given value of the ratio $\frac{R_1}{R_0}$ in which R_1 represents the exterior and R_0 the interior radius of the piece.

Considering the section in front of the powder chamber, we have R_0 equal 4 and R_1 equal 16 inches and, as representing the forces which would cause the limit of elastic displacement of the metal to be reached under tests of free specimens, the following values are considered fair, viz.:

$\rho=40,000$, $\theta=35,000$ pounds per square inch.

The following equation gives the value of the interior pressure or the elastic resistance upon the supposition that the surface of the bore undergoes a range of dilatation, from the state of tangential compression represented by ρ to the state of tangential extension represented by θ, viz.:

$$P = \frac{3\,(R_1^2-R_0^2)}{4R_1^2+2R_0^2}\,(\rho+\theta) \text{ .... } (1)^*$$

The relation between P and θ, such that for a given value of P, θ or the tangential extension (otherwise expressed by $\frac{\Delta r}{r}E=\theta$) shall have a uniform value throughout the thickness of the wall, is expressed by the following equation, viz.:

$$\theta = \frac{2}{3}\,\frac{P}{\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}}-1} = aP \text{ .... } (2)\dagger$$

---

* Derived from Equation (A) page 27, Note 35, making $l=0$. Strictly speaking, the maximum resistance, in any case, should be limited to preserve the metal from excessive displacement whether by tangential extension or radical compression (in state of action), but the *initial state* which would insure a maximum resistance is the same in either case, and for the present we will neglect the limit of radial compression which would give a less value for P and would be derived from equation (B) page 27, Note 35.

† Deduced by Lieut. Wm. Crozier, Ordnance Department, U. S. A., as follows:

From the first of the expressions, page 3, Note 35, with $q=0$, we have: $\frac{\Delta r}{r}=\frac{1}{E}\left(t+\frac{p}{3}\right)=\frac{\theta}{E}$

$$\text{whence } \theta = t+\frac{p}{3} \text{ ....(a)}$$

The interior pressure estimated for any radius r intermediate between R_0 and R_1 will be in equilibrium with the sum of all the tensions acting in the thickness R_1-r, and we have:

$$p\,r = -\int_{R_1}^{r} t\,dr = -\int_{R_1}^{r}\left(\theta-\frac{p}{3}\right)dr$$

Differentiating and reducing,

$$p\,dr + r\,dp = -\left(\theta-\frac{p}{3}\right)dr,$$

$$r\,dp = \left(-\theta+\frac{p}{3}-p\right)dr = -\left(\theta+\frac{2}{3}p\right)dr$$

$$\frac{dp}{\theta+\frac{2}{3}p} = -\frac{dr}{r} \text{ ....(b)}$$

Intergrating between the limits r and R_1

$$\frac{3}{2}\,l\left(\theta+\frac{2}{3}p\right) = -lr + lC$$

For $r=R_1$, $p=0$, then:

$$\frac{3}{2}\,l\left(\theta+\frac{2}{3}p\right)-\frac{3}{2}\,l\theta = lR_1 - lr$$

$$l\left[\frac{\left(\theta+\frac{2}{3}p\right)^{\frac{3}{2}}}{\theta^{\frac{3}{2}}}\right] = l\left(\frac{R_1}{r}\right)$$

$$\left(\theta+\frac{2}{3}p\right)^{\frac{3}{2}} = \frac{R_1}{r}\,\theta^{\frac{3}{2}}$$

$$p = \frac{3}{2}\,\theta\left[\left(\frac{R_1}{r}\right)^{\frac{2}{3}}-1\right] \text{ ....(c)}$$

Substituting the value of θ from (2) in (1), combining the two equations, we find :

$$P = \frac{3\,(R_1^2 - R_0^2)\,\rho}{(4\,R_1^2 + 2\,R_1^2) - 3\,(R_1^2 - R_0^2)\,a} \quad \ldots\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

It is evident from this equation that the greatest possible value for ρ will give a maximum value for P. Substituting known values ($\rho = 40{,}000$, etc.), we find :

$$P = 38910 \text{ pounds per sq. inch,}$$

and, this value in (2) gives: $\theta = 17067$ pounds per sq. inch, from which $\frac{\Delta r}{r} =$ 0.00058852 is the extension per linear inch, uniform through the thickness of the wall for P = 38910. Since P. is a maximum, this value of θ is also a maximum under the condition for both, that θ shall be uniform. This condition is introduced principally with reference to a discussion of the state of rest of the system, to give a datum line from which to lay off the ordinates of the curve of initial tension as shown hereafter. The maximum value of P, if we admit the full limit of tangential extension, is, properly speaking, 51,150 pounds which is the value corresponding to $\theta = 35{,}000$ pounds, and is derived from equation (1). The particular state where θ is uniform and equal to 17,067 pounds and P is equal to 38,910 pounds, marks an intermediate stage which, however, is entirely compatible with the greatest value for P, viz. : 51,150 pounds. We ought not, however, to consider this latter an entirely safe pressure for the gun since, as might readily be shown, this pressure would cause the laminæ near the surface of the bore to be over-compressed in a *radial* direction. The limit of tangential compression of bore, system at rest, being represented as before by $\rho = 40{,}000$, the value of P which would cause the limit of radial compression to be reached in the state of action, is given by the following :

$$P = \frac{2\,(R_1^2 - R_0^2)}{2\,R_1^2 - R_0^2}\,\rho = 38{,}710 \text{ pounds} \ldots\ldots\ldots\ldots\ \ldots\ldots\ldots\ldots (4)^*$$

This is the safe theoretical value for the pressure to which the gun might be subjected ; it corresponds nearly with the value (38,910) which we have found would produce the uniform extension, $\theta = 17{,}067$ pounds, throughout the wall, and it would therefore be a good value to adopt in practice. The thickness here used ($1\frac{1}{2}$ calibres) would probably be a good value to adopt for a steel-cast gun made with initial tension.

CURVE OF INITIAL TENSION.

We now pass to a consideration of the system at rest — that is, the state in which the interior pressure P is supposed removed. The curve of initial tension which shown in Fig. 1 (Plate IV.) is laid off for values of ρ below the middle line, and for values of θ above that line. These values are equivalent to $\frac{\Delta r}{r}$ E and if we divide through by E for the several points of the curve, we would obtain values representing the displacements of the metal at such points and the curve does, properly speaking, represent the displacements (corresponding to ρ or θ) caused by the joint action of the radial pressure (p′) and tangential tension (t′) acting at the circumference described by radius *r*.

Substituting R_0 for r, p becomes P, then

$$P = \tfrac{2}{3}\,\theta\left[\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}} - 1\right]. \ \ldots\ldots\ldots (d)$$

Whence

$$\theta = \tfrac{3}{2}\,\frac{P}{\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}} - 1} \ \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

* From equation (B) page 27, note 35, making l = o.

In any state which we may consider (within proper limits of elasticity) the force θ at a radius r, which is created by the action of the interior pressure P, is expressed by the following.*

$$\theta=\left(\frac{2\,R_0^3}{3(R_1^3-R_0^3)}+\frac{4\,R_1^3\,R_0^3}{3(R_1^3-R_0^3)}\times\frac{1}{r^3}\right)P\ldots\ldots\ldots(5)$$

If we substitute — P for P the resulting value of θ will give the *change* that occurs in θ for the given variation in the pressure. We take that particular state of the system in which $\theta=17{,}067$ pounds is uniform throughout the wall, and for which P $=38{,}910$. Then from the horizontal line which represented this value of θ in Fig. 1, we may lay off the several values found for changes in θ corresponding to given values of r. To refer the points of the resulting curve to the zero line of the figure, and substituting P $=$ — P $=$ —38,910, the above equation is written,

$$\theta\,(\rho)=-\left(\frac{2\,R_0^3}{3(R_1^3-R_0^3)}+\frac{4\,R_1^3\,R_0^3}{3(R_1^3-R_0^3)}\,\frac{1}{r^3}\right)\,38{,}910+17{,}067\ldots\ldots(6)$$

The values of θ for $r=4''.0$, $4''.75$, $6''.0$, $8''.0$, $10''.0$, $12''.0$, $14''.0$ and $16''.0$ are laid off in the figure to locate the curve, and are given in Table A which follows.

It will be observed that at the point where the curve crosses the middle line the displacement is zero. The particular value of r for this neutral point is expressed as follows.†

$$r^3=\frac{2\,R_1^3\,R_0^3\left[\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}}-1\right]}{R_1^3-R_0^3\left(\frac{R_1}{R_0}\right)^{2/3}}\ldots\ldots\ldots(7)$$

This value depends only upon the fixed dimensions of the cylinder; it is independent of the magnitude of the initial tension, hence, for a cylinder of given dimensions, every curve of initial tension (within proper limits) which might occur should pass through the same point. If the neutral point were found much removed from the place indicated it would afford evidence of fault and probably hurtful strains. At the same time, also, there might be dangerous local strains, counterbalancing in effect, even though the neutral point were found at its true position. A good idea of the adequacy of the initial tension would be had by observing the expansion of a thin ring of metal detached next the surface of the bore, but in order to make a proper examination an entire section of the casting should be divided into thin rings as exemplified in Notes on the Construction of Ordnance No. 38. It would, of course, be necessary to make this examination, at least in part, in order to locate the neutral point.

The remaining curves shown on figures 1 and 2, Plate IV., are deduced as follows:

First, take the state of action corresponding to P $=38{,}910$ and $\theta=17{,}067$ constant throughout the wall. The two forces whose combined action produces the curve of uniform extension $\left(\frac{\Delta r}{r}E=\theta\right)$ corresponding to θ are the radial pressure and tangential tension p and t, and the equations of their curves are given by formulas (c) and (a), viz.:

$$p={}^3/_2\theta\left[\left(\frac{R_1}{r}\right)^{\frac{2}{3}}-1\right]\ldots\ldots\ldots\ldots\ldots\ldots(c)$$

$$t=\theta-\tfrac{1}{3}\,p\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(a)$$

---

* From equation (6) page 4, Note 35, making as should be in the case $P'=\theta$.

† For this point, θ has the value given by the equation (2) or $\theta=\tfrac{2}{3}\dfrac{P}{\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}-1}}$. Substituting this value for θ in the first member of equation (5) dividing through by P and reducing, we obtain the equation.

or, by combining these, the value of t expressed directly in terms of θ and dimensions of the cylinder becomes :

$$t = \theta \left\{ 1 - \tfrac{1}{3}\left[\left(\frac{R_1}{r}\right)^{2} - 1\right] \right\} \ldots\ldots\ldots\ldots(a)$$

Again, considering this particular state of action, we may pass to the state of rest by assuming the interior pressure removed which is indicated by making $P = -P$ as was done to determine the curve of initial tension. The variation in the pressure at any point for radius r, corresponding to a variation in F is expressed by the formula *

$$p_1 = \frac{R_0^2\ (R_1^2 - r_n^2)}{r_n^2\ (R_1^2 - R_0^2)}\ p_0 = -1\ P \ldots\ \ldots(8)$$

p_0 is placed equal to—P, and this value being assigned evidently indicates the removal of the interior pressure, hence p_1 gives the variation of pressure in passing from the state of action to the state of rest. The pressure existing in the state of rest is then the algebraic sum of the pressure previously existing for the radius r in the state of action and the variation of that pressure, hence :

$$p' = p + p_1 \ldots\ \ldots\ldots\ \ldots\ldots\ (9)$$

The values of p to be introduced here are to be found from equation (c). The deduced values of p' give the curve of pressure for the state of rest shown in Fig. 1.

For the curve of tension in that state we have, similar to (a)

$$t' = \theta\,(\rho) - \tfrac{1}{3}\,p' \ldots\ldots\ldots\ldots\ldots\ldots\ (10)$$

in which the values of θ are to be found from equation (6).

As before remarked, the curve of initial tension represents a curve of displacements due to the aggregate effect of the forces p' and t'.

Returning to the state of action shown in Fig. 2, and considering the pressure P increased from 38,910 to 51,150 pounds, we have a positive variation of 51,150—38,910 = 12,240 pounds in the value of P. The variations in the value of θ corresponding to this variation will be laid off in a positive direction from the line of uniform extension $\theta = 17{,}067$, but in order to refer to the middle line of the figure as the datum line we use the form of equation (6). The curve of extensions for P = 51,150, is then determined by

$$\theta = \left(\frac{2R_0}{3(R_1^2 - R_0^2)} + \frac{4R_1^2\ R_0^2}{3(R_1^2 - R_0^2)} \times \frac{1}{rr}\right) P + 17{,}067 \ldots\ldots(11)$$

in which P is equal to 12,240 pounds.†

The ordinates for the several curves as determined by the equations given for progressive values of r, together with the displacement per linear inch corresponding to ρ and θ, are given in the following table. The modulus of elasticity E is assumed to be 29,000,000 pounds. (See Table A.)

The indicated strains (values of $\frac{\Delta r}{r}$) under "Initial tension curve" are expressed in terms of the displacements per linear inch ; they are negative or compressions from the bore to the neutral point and positive or extensions thence to the exterior.

The section to be examined should be preferably first turned and bored to the dimensions of the finished piece and then cut into concentric rings, say one inch in thickness. Before cutting, a light circle should be scored on the middle of the face of

* The simplest form of equation (33), page 26, Note 35, when $E_0 = E_1$ (2 cylinders).

† The curve designated Approximate pressure curve for P=51,150 is so far fixed only by the ordinates at the extremities. The interior one is given and the exterior pressure is only the atmospheric pressure which is counted *nil*. The form of (8) and (9) would be applied to determine intermediate points of the curve.

TABLE A.

Radius.	State of Action.							State of Rest.			
	Interior Pressure, 38910 Pounds.				Interior Pressure, 51150 Pounds.			Pressure.	Initial Tension Curve. (Compress's and Exten's)		Tension.
	Pressure.	Extensions.		Tension.	Pressure.	Extensions.					
	p	o	$\frac{\Delta r}{r}$	t	p	o	$\frac{\Delta r}{r}$	p′	p & o	$\frac{\Delta r}{r}$	t'
Inches.	Pounds.	Pounds.	Thousandths	Pounds.	Pounds.	Pounds.	Thousandths	Pounds.	Pounds.	Thousandths.	Pounds.
Ro-4.0	38910	17067	0.58852	4150	51150	35000	1.207	0.	− 40000	− 1.3793	− 40000
4.75	31930	"	"	6425	——	——	——	5090	− 23905	− 0.82431	− 25600
6.0	23630	"	"	9190	——	25340	0.8738	7780	− 9260	− 0.3193	− 11850
*7.6	16460	"	"	11580	——	——	——	7550	0.	0.00000	− 2520
8.0	15040	"	"	12055	——	21960	0.75725	7255	+ 1505	+ 0.0519	− 920
10.0	9420	"	"	13930	——	20395	0.70327	5375	+ 6485	+ 0.22362	+ 4695
12.0	5410	"	"	15265	——	19545	0.67305	2875	+ 9190	+ 0.31690	+ 8230
14.0	2385	"	"	16275	——	19030	0.65621	1590	+ 10820	+ 0.37310	+ 10290
R_1-16.0	0	"	"	17067	0.	18700	0.64483	0.	+ 11880	+ 0.40965	+ 11880

* Neutral point of initial tension curve.

each ring and several diameters carefully measured. These measurements repeated after the separation of the ring will give a measure of the force, whether positive or negative, by which the ring was held in restraint. The mean expansion or contraction divided by the diameter of the measured circle will give the value corresponding to $\frac{\Delta r}{r}$ and this quotient multiplied by the modulus of elasticity of the metal will give the value ρ or θ corresponding respectively to the measured expansion or contraction. If the diameter be called D, and the measured change of diameter d, the expressions are as follows: *

$$\frac{D}{+d}E=\rho \text{ and } \frac{D}{-d}E=\theta \text{ ....(11)a}$$

The powder chamber would be made, we will say, with a diameter of 9.5 inches, or $R_0=4.75$. In order to avoid the disturbance of the initial state which would result from enlarging to this size a bore made somewhat less than 8 inches in the rough, it would appear advisable to make the chamber nearly full size in the rough form before introducing the initial tension by either method that might be used. However this may be, the uncertainties of the manufacture are such that it is unimportant to consider here the disturbance which might arise in reaming out the chamber, and we will assume the interior surface there to be also compressed tangentially to the limit $\rho=40,000$.

Applying equation (1) we find for the limit of tangential action (to compare with $P=51,150$ for the section in front of the chamber).

$P=49,130$ pounds per sq. inch.

The value which P would have when the extension θ became uniform throughout the wall is found from equation (3), viz.: $P=40,320$, and the corresponding value of the uniform extension from equation (2), is: $\theta=21,554$. Observe in this case that the values of P and θ for this particular state of action are both greater than for the corresponding state for the thicker section in front of the powder chamber where $P=38,910$ and $\theta=17,067$.

The values of P which we have just discussed would cause the radial compression at the surface of the bore to be exceeded in the state of action. Based on this limit the value of P for the chamber section, derived from equation (4) would be 38,156 pounds to compare with a similar value of 38,710 pounds for the section in front of the chamber. It will be generally considered safest and best not to subject a gun to pressures much exceeding the value of P here indicated.

If it were desired to evaluate the change in tangential compression of bore due to reaming out the chamber it may be found from the equation

$$\rho_r=\frac{R_1^2-R_0^2}{R_1^2-r_0^2}\rho_0 \text{ ....(11)b}$$

in which r_0 represents the radius of the enlarged bore and ρ_r the tangential compression per sq. inch at the surface. Thus if the tangential compression, $\rho_0=40,000$, existed for a bore of 8 inches and if this were bored out to 9.5 inches, whence $r_0=4.75$, then we find $\rho_r=41,125$ or the increase of compression due to the removal of this amount of metal would be 1125 pounds per square inch. A close adherence to principles would require that the value of ρ_r should be limited to 40,000; and substituting this in (11)b and solving with reference to ρ_0 we find $\rho_0=38,900$ which represents the initial compression which it should be aimed to obtain in a casting of 8-inch bore intended to be afterwards bored out to 9.5 inches.

* The method of conducting this test is explained in Notes on the Construction of Ordnance, No. 38.

CHARACTERISTICS OF THE RESISTANCE OF CYLINDERS DEPENDING UPON RADIAL DIMENSIONS AND MODE OF CONSTRUCTION.

It will be seen that the values of P from equation (1) for the limit of tangential action decrease with the thickness of the wall, whilst those of P from equation (3) involving the uniformity of strain increase as the thickness decreases. This may be readily seen, also, from an inspection of the equations, and if we should plot the loci of the values of P, considering R_0 as a variable with successively increased values, from equation (1) and (3) the two lines would intersect within the limits of the wall. The value of the radius R_0 corresponding to this point of intersection where the two values of P are equal, marks the interior radius of a cylinder (supposing R_1 to remain 16 inches and the constants θ and ρ as before) in which the extension is uniform and equal to the limit (θ) 35,000 when P has its maximum value for the limit of tangential action. In a cylinder with such interior radius the whole of the metal would be worked to its tangential limit, and there would be a maximum utilization of the metal in the resistance offered to an interior pressure.

To make the case more general let us find the value of the ratio $\frac{R_1}{R_0} = b$ such that θ shall be uniform throughout the wall and equal to its maximum value when P is a maximum, for any cylinder.

The two equations of condition are (1) and (2); we must equate the value of P from these and find $\frac{R_1}{R_0}$. Placing the values of P from (1) and (2) equal, we have:

$$\frac{3}{2}\theta\left[\left(\frac{R_1}{R_0}\right)^{2/3} - 1\right] = \frac{3(R_1^2 - R_0^2)}{4R_1^2 + 2R_0^2}(\theta + \rho)$$

Substituting $b = \frac{R_1}{R_0}$ and reducing

$$\theta b^{\frac{2}{3}} - \theta = \frac{b^2 - 1}{2b^2 + 2}(\theta + \rho)$$

whence $b^{\frac{8}{3}} - \frac{3\theta + \rho}{2\theta} b^2 + 0.5\, b^{\frac{2}{3}} + \frac{\rho}{2\theta} = 0$ . . . .(12)

From this equation, substituting $\rho = 40{,}000$, and $\theta = 35{,}000$, we find

$$b = 2.4722.$$

This value applies to the particular case in question where $\theta = 35{,}000$ and $\rho = 40{,}000$. If we retain $R_1 = 16$, we have $R_0 = \frac{R_1}{b} = 6.472$ incbes or a bore of 12.94 inches, and a thickness of wall of 6.53 inches instead of 12 inches, as originally considered in the section in front of the chamber. With this new value of R_0 and given constants we find the value of P from either of equations (1) (2) or (3) to be 43,490 pounds. The maximum resistance is of course decreased (from 51,150 pounds) by this decrease of the thickness, but the given ratio determines the least weight of metal that will withstand an interior pressure of 43,490 pounds, and also indicates the most economical use of the metal considering the tangential limit of extension alone. If the interior radius be fixed, as, for instance, $R_0 = 4.75$ (chamber section) we find $R_1 = b \times 475 = 11.743$, or a cylinder with 9.5 interior and 23.49 exterior diameter should support this pressure of 43.490 pounds.

If $\theta = \rho$, equation (12) becomes:

$$b^{\frac{8}{3}} - 2b^2 + 0.5\, b^{\frac{2}{3}} + 0.5 = 0 \quad . \quad . \quad . \quad (13)$$

and from this we find,

$$b = 2.2946.$$

Then in any case, if $\theta = \rho$. the Ratio $\dfrac{R_1}{R_0} = 2.3$ will, if R_0, or R_1 be assumed, fix the dimensions of a cylinder (made with full initial tension or assembled under such shrinkage that the compression of the bore shall equal θ), which will give a maximum resistance to tangential extension for the least weight of metal.

From this value of b we find the thickness of the wall expressed in terms of the interior radius :

$$b = \frac{R_1}{R_0} = 2.2946.$$

and $\qquad R_1 - R_0 = 1.2946\ R_0.$

If the walls were thicker than $1.3\ R_0$, the condition of uniform extension expressed by equation (3) would be reached before the resistance of the gun was fully developed : if the wall were of less thickness than $1.3\ R_0$ the state of uniform extension could not be reached without the tangential extension exceeding the limit θ.

If we equate the values of P from equations (1) and (4) we can determine a value for the ratio $\dfrac{R_1}{R_0}$ such that the limits of tangential extension and of radial compression would be simultaneously reached in the state of action. We have, supposing $\rho = \theta$, from equations (1) and (4)

$$\frac{3(R_1^2 - R_0^2)}{4\ R_1^2 + 2R_0} (\rho + \theta = \frac{2(R_1^2 - R_0^2)}{2\ R_1^2 - R_0} \rho$$

Making $\rho = \theta$, and reducing, also placing $\dfrac{R_1}{R_0} = C$;

$$\frac{3}{2\ C^2 + 1} = \frac{2}{2\ C^2 - 1}$$

whence

$$C = \sqrt{\tfrac{5}{2}} = 1.581,$$

Or, in terms of the thickness and the interior radius,

$$R_1 - R_0 = 0.58\ R_0.$$

From this last it appears that if the thickness of wall exceeds $0.58\ R_0$, the cylinder will first fail, in action, from radial compression and the theoretically safe value of P would be derived from equation (4). If the thickness were less than $0.58\ R_0$ the cylinder would fail first from tangential extension, and equation (1) would be applied to find the value of P. These discussions will be understood to refer to a cylinder having full initial tension, and generally to a built-up gun in which the tube is compressed to the limit in the state of rest.

If we consider a simple cylinder without initial tension the limit of safety would always first be passed under tangential extension when subjected to an interior pressure only. The equations which give the pressure to be safely supported in this case are for tangential extension and radial compression respectively. (See page 6, Note 35) :

$$P(^1) = \frac{3(R_1^2 - R_0^2)}{4\ R_1^2 + 2\ R_0^2}\theta, \qquad P(^2) = \frac{3\ (R_1^2 - R_0^2)}{4\ R_1^2 - 2\ R_0^2}\rho$$

Since the denominator of the first exceeds that of the second in the sum of $4R_0^2$ and since θ is for the metals used in gun construction, either equal to or less than ρ, the safe, that is the least value of P will be found from the first equation which corresponds to the limit of tangential resistance.